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IRON BLAST-FURNACE REACTIONS

BY

S. P. KINNEY, P. H. ROYSTER, and T. L. JOSEPH

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IRON BLAST-FURNACE REACTIONS

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INTRODUCTION

Exact knowledge of the chemical and metallurgical reactions in the interior of the blast furnace is becoming increasingly important to furnace operators. With a view to providing basic data and thus aiding the iron and steel industry, the Bureau of Mines has attempted to determine the reactions as they take place in the interior of the furnace. In this work the bureau used two methods of attack: (1) A study of the composition of the gases across a series of planes between the tuyère level and the stock line, and (2) a study of the composition of stock samples removed from various planes. The investigation reported in this paper is analogous to a number of others that the bureau has conducted, at its Minneapolis, Pittsburgh, and Birmingham-Tuscaloosa experiment stations, on the reduction of iron oxides and the combustibility of coke.

In the study of the combustibility of coke a survey was made of the combustion zones of 14 blast furnaces. Methods were developed for obtaining gas samples at intervals across the tuyère planes of the furnaces, and these methods were later applied to a number of experimental furnaces at the bureau's North Central station, where the study of combustibility was continued and compared with the results obtained in full-size furnaces. Here the methods developed in the study of combustibility were applied to a study of the reduction of iron oxides, by means of gas sampling across a series of planes between the tuyère level and the stock line. These experiments included taking several thousand gas samples in the hearth planes of the industrial furnaces and in the series of planes in the upper part of the experimental furnaces.

The work on the reduction of iron oxides in the experimental furnace has been discussed in a series of papers[1] by the authors, and a report on the combustion of coke in the blast-furnace hearth has been

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[1] Royster, P. H., Joseph, T. L., and Kinney, S. P., "Reduction of iron ore in the blast furnace": Blast Furnace and Steel Plant, vol. 12, 1924, pp. 35–38. "Significance of hearth temperatures": Ibid., pp. 97–101. "Heat balance of Bureau of Mines experimental furnace": Ibid., pp. 200–204. "Time element in iron-ore reduction": Ibid., pp. 246–250. "Influence of ore size on reduction": Ibid., pp. 274–280.

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made by Perrott and Kinney.[2] Other papers[3] on the combustibility of coke have been written by Kinney, Perrott and Fieldner, Fieldner, Sherman and Blizard, Sherman and Kinney, and Sherman.

For comparison of the results obtained in the experimental furnace with actual practice, study of the reduction of iron oxides was extended to a 300-ton furnace, where the gases were sampled across a series of planes lying between the tuyère level and the stock line. This paper describes and discusses the work done.

SUMMARY OF FINDINGS AND SUGGESTED CHANGES IN FURNACE DESIGN

Samples of gases from various planes in the furnace have shown that certain parts of the furnace do more work than others because the stock moves unevenly. Ideal operation would seem to require uniform flow of stock and gas. As it has been shown that the combustion zones control the movement of stock in the furnace, Kinney and McKenzie[4] have suggested that more uniform movement might be obtained by rearrangement of these zones in an elliptical or oval hearth, not wider than twice the length of the zone of combustion. By so doing the average temperature of the hearth would be higher than in present furnaces and combustion would be proceeding uniformly throughout the hearth area; therefore stock movement would be uniform in the stack.

ACKNOWLEDGMENTS

Much credit is due the officials and men of the Central Iron & Coal Co., Holt, Ala., for their hearty cooperation and help. The desire of this company to learn something of the reactions in the interior of its furnace was demonstrated by the drilling of holes in the shell of a comparatively newly lined furnace and by the expenditure of considerable money, energy, and material to make the investigation a success. The authors especially wish to acknowledge the aid given by R. R. Rust, president; J. L. Brierton, vice president and general manager; Fraser B. McKenzie, blast-furnace superintendent; W. Z. Reynolds; and H. S. Landers, chief chemist. Acknowledgment is also made to D. A. Lyon, chief metallurgist, of the Bureau of Mines, under whose direction the investigation was conducted; A. C.

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[2] Perrott, G. St. J., and Kinney, S. P., "Combustion of coke in the blast-furnace hearth": Trans. Am. Inst. Min. and Met. Eng., vol. 69, 1923, pp. 543–584.

[3] Kinney, S. P., "Combustion of coke at the tuyère level of the blast furnace": Blast Furnace and Steel Plant, vol. 13, 1925, pp. 243–247. "Relation of carbon consumption to material smelted in the blast furnace": Ibid., vol. 14, 1926, pp. 15, 24; Fuels and Furnaces, vol. 4, No. 1, 1926, pp. 77, 78, 116.

Perrott, G. St. J., and Fieldner, A. C., "The properties of metallurgical coke": Proc. Am. Soc. Test. Mat., vol. 23, 1923, pp. 475–493; discussion, pp. 494–500.

Fieldner, A. C., "Combustibility of coke"; paper read before Am. Inst. Chem. Eng., Washington, Dec. 5, 1923; reprinted in Chem. and Met. Eng., vol. 29, 1923, pp. 1052–1057.

Sherman, R. A., and Blizard, John, "Combustion of blast-furnace coke in fuel beds": Trans. Am. Inst. Min. and Met. Eng., 1923, vol. 69, 1923, pp. 526–542; discussion, pp. 584–586.

Sherman, R. A., and Kinney, S. P., "Combustibility of blast-furnace coke"; paper read at Eastern States Blast Furnace and Coke-Oven Assoc., South Bethlehem, Pa., May 23, 1923; reprinted in Iron Age, vol. 111, 1923, pp. 1839–1844.

Sherman, R. A., "Combustibility of blast-furnace coke": Iron Age, vol. 115, 1925, pp. 1043–1045.

[4] Kinney, S. P., and McKenzie, F. B., "Proposed bosh and hearth construction": Iron Age, vol. 115, 1925, pp. 476–7; discussion, p. 707.

Fieldner, chief chemist of the bureau and superintendent of the Pittsburgh experiment station; and M. W. von Bernewitz, mining and metallurgical engineer.

PREVIOUS WORK

Many investigators have attempted to study the reactions at various elevations in the blast furnace. Usually the data have been obtained by taking gas samples at a single point through holes punctured in the shell of the furnace or by allowing a vertical pipe to descend with the stock. A few investigators reported temperatures and pressures. The first work available is a report by Bunsen and Playfair in 1845 at Alferton, England, who studied a furnace that used anthracite fuel. Table 1 gives a chronological list of investigations, arranged by fuels. Most of these have been reported [5] in some detail by Wedding, Percy, Bell, Von Jüptner, and Mathesius.

TABLE 1.—*List of previous investigations of the blast furnace*

Investigator	Year	Place and country	Fuel used	Reference and remarks
Bunsen and Playfair.	1845	Alferton, England	Anthracite.	Bunsen, R. W., and Playfair, L., "Theory of iron smelting": Rept. British Assoc. Adv. Sci., Cambridge, England, 1845, pp. 142–186. Wedding, Herman, work cited.
Ebelmen	1841	Audincourt, France	Charcoal	Ebelmen, A. D., Tranv. Scient., 1841, p. 315.
Bunsen	1838	Veckerhagen, Prussia	do	Bunsen, R. W., work cited.
Ebelmen	1841	Clerval, France	do	Ebelmen, A. D., work cited.
Heine	1842	Magdesprung, Harz	do	Percy, John, work cited, p. 433.
Scheerer and Langberg.	1843	Barum, Norway	do	Do.
Ebelmen	1848	Clerval, France	do	Ebelmen, A. D., Tranv. Scient., vol. 2, 1840, p. 420.
Turner and Richter	1860	Eisenerz, Stiermark, Austria. Wamba furnace.[a]	do	Turner and Richter, Turners Jahrb., vol. 9, 1860, p. 281.
Do	1860	Eisenerz, Stiermark, Austria. Kaiser Franz furnace.[a]	do	Do.
Rinman and Fernquist.	1862	Hammarby, Sweden [a]	do	Percy, John, work cited, p. 430.
Do	1863	Forssjo, Sweden [a]	do	Do.
Do	1864	Hasselfors, Sweden [a]	do	Do.
Rinman	1866	Harnas, Sweden [a]	do	Percy, John, work cited, p. 431.
Kupelwieser and Schoffel.	1873	Eisenerz, Stiermark, Austria.[b]	do	Do.
Ebelmen	1843	Vienne, France	Coke	Ebelmen, A. D., Tranv. Scient., vol. 2, 1848, p. 420.
Do	1843	Pont-l'Eveque, France [a]	do	Do.
Do	1843	Searing, Belgium	do	Percy, John, work cited, p. 432.
Bell	1871	Wear Furnace, England	do	Bell, I. L., work cited.
Levin and Niedt	1911	Silesia, Germany [a]	do	Levin, M., and Niedt, H., "Untersuchungen über Zusammensetzung des Gasstromes im Hochofen: Metallurgie, Jahrg. 8, 1911, pp. 515–539, 556–581; Stahl u. Eisen, Jahrg. 31, 1911, p. 21–35.
Do	1911	Rhineland, Germany [a]	do	Do.
Schlesinger	1911	Oberhausen, Germany [a]	do	Metz, Norbert, "Studien über die Vorgänge im Hochofen"; Stahl u. Eisen, Jahrg. 33, 1913, pp. 93–104.
Metz	1913	Dudelingen, Luxemburg.[b]	do	Do.

[a] Temperatures and pressures measured.

[b] Temperatures measured.

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[5] Wedding, Hermann, Handbuch der Eisenhüttenkunde. 2d ed., Braunschweig, 1896, vol. 3, pp. 203–241.
Percy, John, Metallurgy. London, 1864, 596 pp.
Bell, I., Chemical Phenomena of Iron Smelting. London, 1872.
von Jüptner, Hanns, Beiträge zur Hochofentheorie. Leipzig, 1921, 320 pp.
Mathesius, Walther, Die Physikalischen und Chemischen Grundlagen des Eisenhüttenwesens. Leipzig, 1924, 439 pp.

RELIABILITY OF PREVIOUS RESULTS

As they covered a wide range of fuels and a number of furnaces the investigations cited in Table 1 furnished particularly valuable data. In all of these investigations, except those of Levin and Niedt and Metz, the gas samples were obtained by introducing an uncooled iron tube in the furnace or by lowering it through the top and allowing it to descend with the stock. The value of the gas samples taken by this method is somewhat doubtful. The iron sample tube might have become oxidized by the gas sample, thus causing a change in the composition of the gas during sampling. Moreover, in all of these investigations the samples were taken over water, a method of collection that is open to criticism because of the solubility of CO_2 in water.

All samples except those of Metz were taken at one point at each elevation. This investigation indicates that such samples, if taken with water-cooled sampling tubes and over mercury, show the composition of the gas at the point at which the samples were taken, but do not represent the reactions at other points in the same plane. A large number of samples must be taken at each point if the results are to be representative. It is further necessary to take samples at several points on any radial line to determine the gas composition along that line. Six planes were available for sampling and there were about 20 sampling points on each. If the reactions in the furnace are uniform and symmetrical, the samples taken on any radius will represent the gas composition on the plane.

The results of Metz and of Levin and Niedt agree with those obtained in this investigation, although those investigators did not obtain comparable data because their observations were limited to a single point on each plane.

FURNACE, APPARATUS USED, AND PROCEDURE OF TESTS

DESCRIPTION OF FURNACE

As already mentioned, this investigation was conducted at a 300-ton southern furnace making foundry iron. The furnace was smelting a mixture of southern red and brown ores [6] (hematite and limonite), and nodules made from pyrite sinter. The flux used was dolomitic and the coke was made from coal from the Brookwood and Mildale beds at Kellerman, Ala.; it was washed before coking. Details of the materials charged and the operation of the furnace are given later.

---

[6] Wingard, J. H., Statistics of the Mineral Production of Alabama for 1921: Bull. 26, Geol. Survey of Alabama, Univ. of Alabama, 1923, 111 pp.; see pp. 66 and 71.

Phillips, W. B., Iron Making in Alabama: Rept. of Geol. Survey of Alabama, 3d ed., Univ. of Alabama, 1912, 254 pp.; see pp. 16–113.

Crane, W. R., Iron Ore (Hematite) Mining Practice in the Birmingham District, Alabama: Bull. 239, Bureau of Mines, 1926, 144 pp. Abstract in vol. 72, Am. Inst. Min. and Met. Eng., 1925, pp. 157–225.

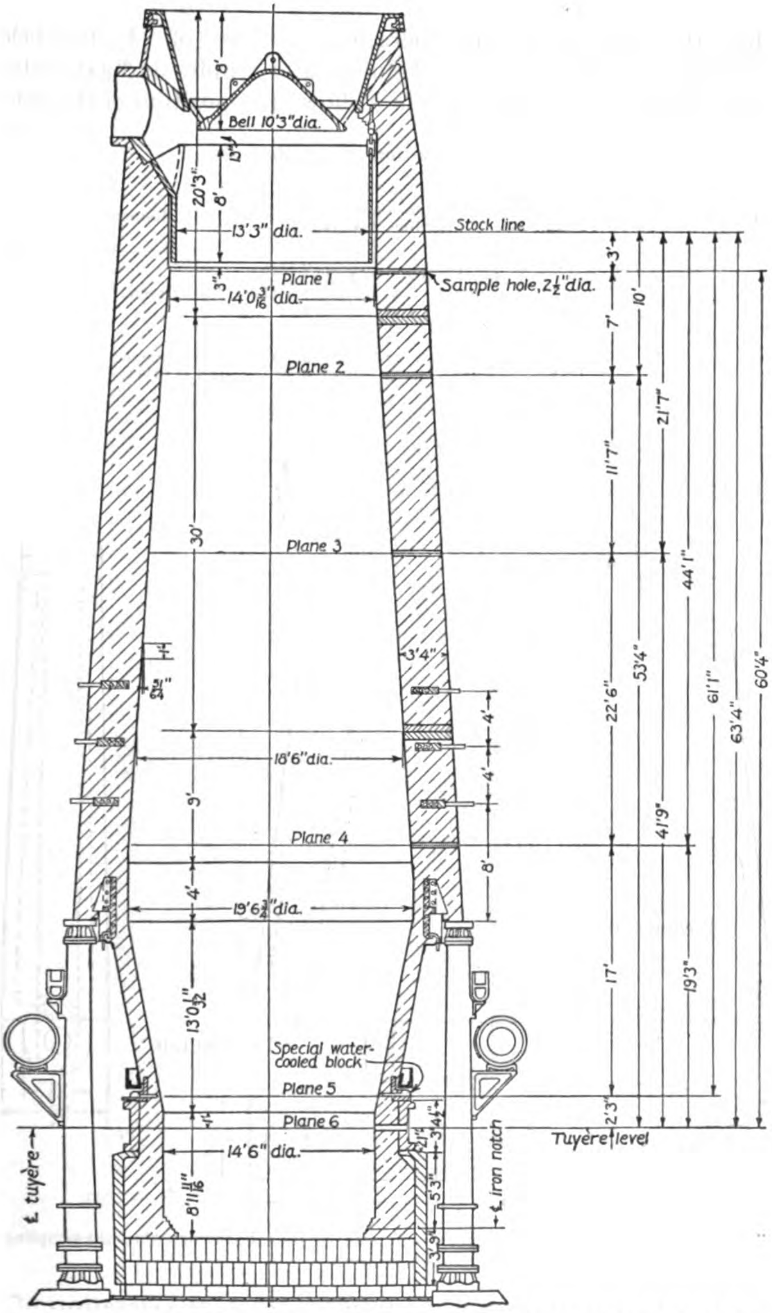

FIGURE 1.—Section of blast furnace, showing holes through lining and shell for taking samples of gas and materials charged

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POSITION OF SAMPLE HOLES

While the furnace was in operation, a series of 2½-inch holes was drilled through the shell and lining, and nipples and gate valves were attached to the shell. Table 2 shows the position of the holes.

TABLE 2.—*Position of sample holes*

Hole No.	Distance below stock line		Distance above center line of tuyères		Remarks
	Feet	*Inches*	*Feet*	*Inches*	
1	3	0	60	4	Above No. 3 tuyère.
2	10	0	53	4	Do.
3	21	7	41	9	Do.
4	44	1	19	3	Do.
5	61	1	2	3	Above cinder notch.
6	63	4	0	0	Nos. 5 and 11 tuyères.

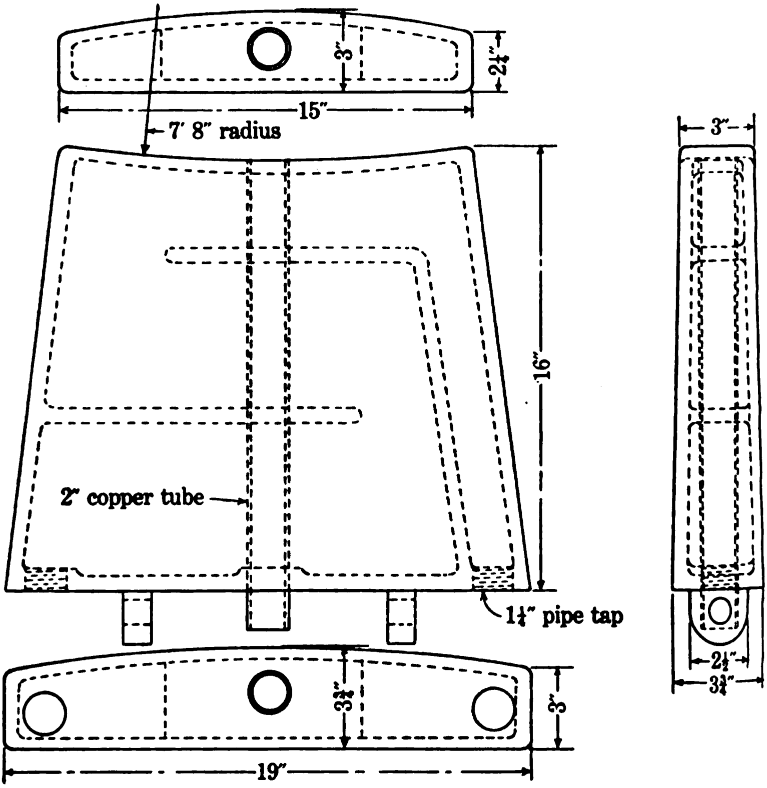


FIGURE 4.—Details of special water-cooled bosh plate, having tube through which gas-sampling tube was driven

Figure 1, a cross section of the furnace, shows the elevation of the six sample holes, and Figure 2 gives a general view of the stack and the platforms for holes 1, 2, and 3. Holes 1, 2, 3, and 4 were directly above one another at one side of the furnace. Hole 5 is in a water-

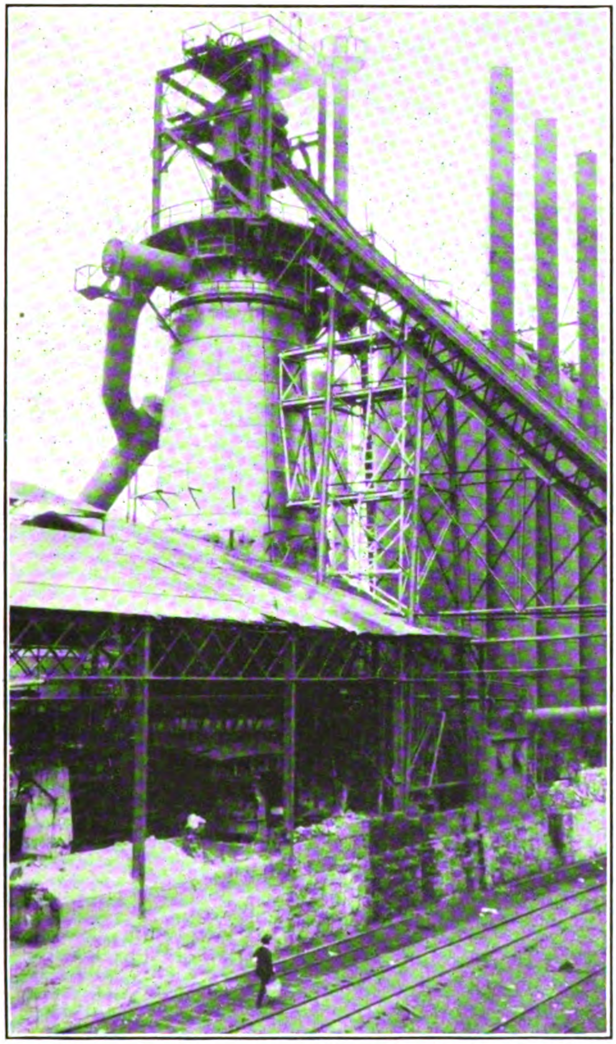


FIGURE 2.—BLAST-FURNACE STACK GAS-SAMPLING PLATFORMS, AND POSITION OF PLANES 1, 2, AND 3

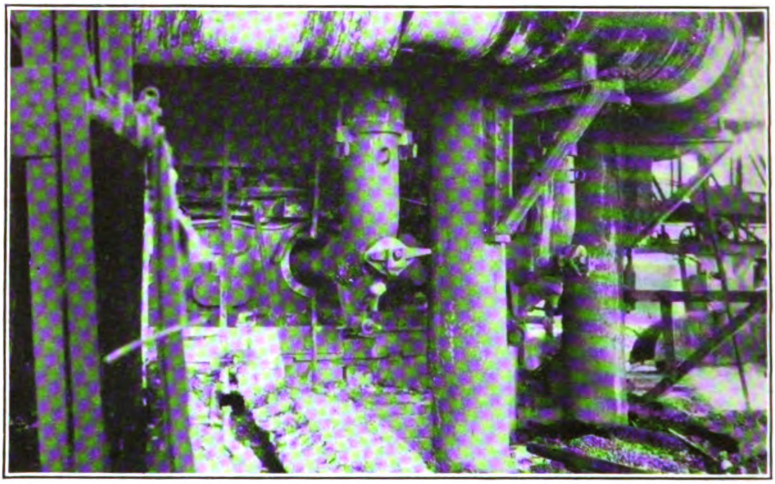


FIGURE 3.—WATER-COOLED PLATE IN BOSH BETWEEN CINDER NOTCH AND NO. 10 TUYÈRE

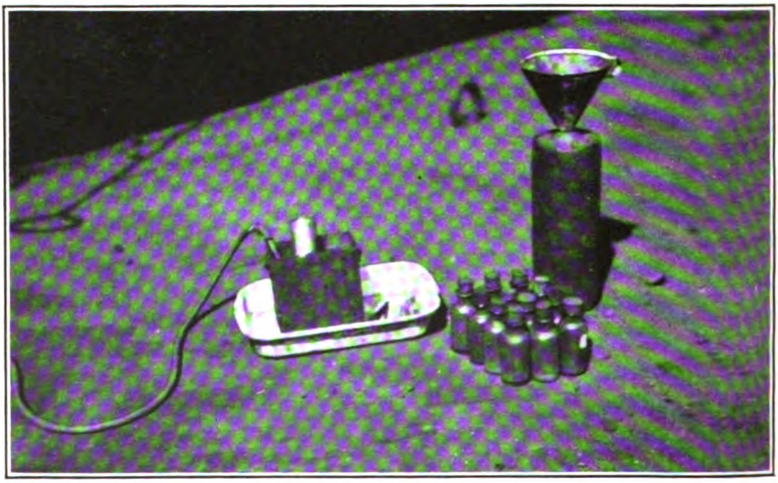
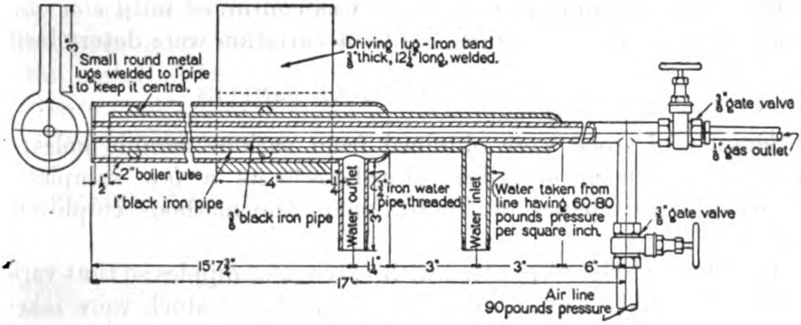


FIGURE 6.—APPARATUS FOR COLLECTING GAS SAMPLES

cooled block in the furnace wall opposite holes 1, 2, 3, and 4. A specially constructed water-cooled bosh plate was set in the bosh of the furnace at an elevation of 27 inches above the center line of the tuyères. As Figure 3 shows, the block was set above and to the left of No. 10 tuyère, which appears in the figure at the right of the cinder notch. Figure 3 shows the position of the center line of the plate in respect to the center line of the tuyère. Figure 4 gives details of the water-cooled plate used—a standard cooling plate through which a 2-inch copper tube has been set, as shown. This tube slightly retarded the circulation of water through the plate, but not enough to cause trouble in the cooling system.

METHOD AND APPARATUS USED IN COLLECTING GAS SAMPLES

As the method of obtaining the gas samples by the use of water-cooled sampling tubes has been described elsewhere,[7] only a short description is given here.



3"
Small round metal lugs welded to 1" pipe to keep it central.
Driving lug - Iron band 3/8" thick, 12 1/4" long, welded.
3/8" gate valve
1/8" gas outlet
1/2"
2" boiler tube
1" black iron pipe
4"
3/8" black iron pipe
1/4"
Water outlet
3/4" iron water pipe, threaded
3"
Water inlet
Water taken from line having 60-80 pounds pressure per square inch.
3/8" gate valve
15'7 3/4"
1 1/4"
3"
3"
6"
17'
Air line 90 pounds pressure

FIGURE 5.—Water-cooled gas-sampling tube

The sampling tube shown in Figure 5 was driven through the opening in the furnace to the center with a dolly bar. At the tuyère plane and bosh, compressed air was used in the center, or gas line, to prevent stoppage with slag or other fused material. When samples were taken on planes higher in the furnace, where fused material was not encountered, a rod was used to prevent the plugging of the gas line. When the tube had been driven to the center of the furnace, the air was disconnected or the rod was removed and a rubber tube was connected to the one-eighth-inch gas outlet pipe. This tube led to the point where the samples were taken (fig. 6). A small hook of one-eighth-inch iron pipe was attached to the end of the rubber tube. At each setting of the sample tube gas samples were collected over mercury in 4-ounce wide-mouth bottles closed with rubber stoppers. After a sample had been taken the bottle was inverted and set in a shallow trough of water, which acted as a

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[7] Perrott, G. St. J., and Kinney, S. P., "Combustion of coke in the blast-furnace hearth": Trans. Am. Inst. Min. and Met. Eng., vol. 69, 1923, pp. 543–584.

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secondary seal. A little mercury was left in each bottle, and when the bottle was inverted the mercury acted as a seal for the gas and as a covering for the rubber stopper.

Analyses for CO_2, O_2, CO, H_2, and N_2 were made in a modified Orsat apparatus[8] of the Burrell type. Two pipettes of the bubbling type, containing acid cuprous chloride, were used for the determination of carbon monoxide.

The collection of gas samples continued over a considerable period. Sampling was started on plane 1, 3 feet under the stock line, and progressed from plane to plane until the tuyère level was reached. All samples were collected when the furnace was operating normally, and if operation seemed irregular the sampling was abandoned until operation was normal. Each plane was sampled on several different days. Each day's work involved repeated sampling of the gases from the inwall to the center of the furnace, at intervals of approximately 4 inches; the distance was covered several times daily. The sampling of each plane was continued until concordant results were obtained and the limits of variation were determined.

COLLECTION OF STOCK SAMPLES

Samples of stock were obtained from various sample holes; the results have been described elsewhere.[9] As a few samples are reported in this paper, a description of the methods employed in collecting is given.

The sample holes were fitted with valves and nipples so that various apparatus could be attached. When samples of stock were taken a pipe was attached to the sample hole, which led downward and to one side to an air-tight container where the hot stock was deposited and allowed to cool. The pipes from the sample hole to the container were short and were so arranged that the holes could be worked with a 1½-inch drill rod or hook.

The samples of stock obtained from the various sample holes were allowed to cool in a reducing atmosphere, then they were examined in the laboratory, where the various constituents of each sample were separated and analyzed.

Samples of coke were taken from various holes and analyzed for total sulphur and the several forms of sulphur. Results of this phase of the investigation will be reported elsewhere.

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[8] Fieldner, A. C., and Jones, G. W., The Bureau of Mines Orsat Apparatus for Gas Analysis: Tech. Paper 320, Bureau of Mines, 1925, 18 pp.

[9] Kinney, S. P., "Analyses of miscellaneous samples of coke, metal, slag, limestone, and stock recovered from various elevations in a blast furnace." To be published in technical press.

SAMPLES OF FUME AND STOCK FOR CYANIDES

Samples of stock and of fume from the gases were collected in the lower part of the furnace and examined for their content of cyanide. The solid stock was collected as above described and the fume from the gas was collected with filters through which a measured quantity of gas was passed; the samples were analyzed for potassium cyanide (KCN) and total alkali. The results of the cyanide investigation will be given in a report[10] published in cooperation with the Department of Agriculture, Fixed-Nitrogen Research Laboratory.

TEMPERATURE AND PRESSURE OBSERVATIONS

Temperature and pressure observations were made at various elevations in the furnace stack. The temperatures at the inwall at holes 1 to 4, inclusive, were taken by means of base-metal and platinum thermocouples. Temperatures were taken at the center of the planes at a number of elevations. The temperature of the center of the hearth at the tuyère level was taken with a platinum thermocouple. Optical pyrometer readings were made of the temperature of the tuyères, metal, and slag.

Pressure readings were made at holes 1, 2, 3, and 4 with mercury and water manometers.

FURNACE-OPERATING DATA AND BALANCE SHEET OF MATERIALS[11]

Tables 3 to 8, inclusive, give miscellaneous operating data and quantities of materials charged and discharged from the furnace. The balance sheet of materials covers a 10-day period of operation and is presented to give an example of the practice. The results in Table 6 for materials discharged have been calculated from actual analysis of discharged materials and adjusted where necessary to complete the balance. The accuracy of the balance may be determined by comparison of the results obtained by actual and calculated analyses, shown in Tables 7 and 8.

---

[10] Kinney, S. P., and Guernsey, E. W., "The occurrence of alkali cyanides in the iron blast furnace": Ind. and Eng. Chem., vol. 17, July, 1925, pp. 670–674. The Occurrence, Distribution, and Significance of Alkali Cyanides in the Iron Blast Furnace: Tech. Paper 390, Bureau of Mines, 1926, 41 pp.

[11] Kinney, S. P., "Materials and heat balance of a southern furnace": Blast Furnace and Steel Plant, vol. 13, July, 1925, pp. 272–276.

TABLE 3.—*Miscellaneous operating data* [a]

	°F.	°C.
Temperatures of:		
Blast	957	513.8
Top	335	168.2
Metal	2,525	1,385
Slag	2,568	1,409
Tuyère	2,793	1,534
Air at blowing engine, dry bulb	65	18.3
Air at blowing engine, wet bulb	56.5	13.6
Relative humidity per cent		55
Moisture in air grains per cubic foot		3.73
Barometer		29.64
Pressures (pounds per square inch):		
Blast		16.85
Steam		88.9
Blowing engine:		
Revolutions per minute		101.5
Air blown, calculated from engine speed, dry, cubic feet per minute at 65° F., and 30 inches of mercury		41,660
Air blown, calculated from carbon consumption and gas analysis—		
Dry, cubic feet per minute at 65° F. and 30 inches of mercury		28,691
Wet, containing 3.73 grains of water per cubic foot		29,012
Coke:		
Shatter test per cent [b]		69
True specific gravity		2.00
Apparent specific gravity		0.99
Furnace data:		
Volume of furnace cubic feet		15,385
Number of tuyères		12
Size of tuyères inches		6 by 12
Charges per day		71.4
Iron made tons per day		324.7

TABLE 4.—*Analyses of raw materials, per cent* [1]

Constituent	Brown ore	Attalla red ore	Estelle red ore	Nodules [2]	Limestone [3]	Coke [4]
H_2O	13.98	1.30	3.88	9.45	0.10	5.40
SiO_2	14.10	10.05	7.74	10.80	1.00	6.76
Al_2O_3	5.70	3.20	4.83	4.20	.60	4.10
Fe_2O_3	61.70	56.10	43.25	53.09	1.00	1.21
FeO	.00	.00	.00	20.61	.00	.00
MnO	1.02	.18	.14	.08	.03	.00
P_2O_5	1.56	.42	.21	.07	.01	.04
CaO	.22	14.80	20.91	.60	30.22	.27
MgO	.22	.30	.90	.10	21.21	.16
K_2O	.30	.80	.60	.30	.00	.17
Na_2O	.30	.30	.50	.20	.00	.06
S	.10	.00	.10	.30	.10	1.02
CO_2	.80	12.10	16.93	.20	45.73	.00
Fixed carbon						80.35
Volatile matter						.46
Total	100.00	100.00	100.00	100.00	100.00	100.00

[1] Analysis as reported by Bureau of Mines.

[2] Nodules made from pyrite sinter.

[3] Dolomite.

[4] Coke made in Semet-Solvay ovens from washed coal. Coal mined from Brookwood and Mildale beds, Kellerman, Ala.

[a] Average values covering period represented by balance sheet of materials.

[b] Percentage of coke remaining on a 2-inch square-mesh screen after 50-pound sample had been dropped four times from a height of 6 feet upon a steel plate.

Table 5.—*Composition of materials charged, pounds per long ton of metal produced*

Constituent	Scrap	Brown ore	Attalla ore	Estelle ore	Nodules	Limestone	Coke	Air	Total	Per cent
H_2O		296.01	8.52	16.98	94.74	1.22	141.65	67.92	627.04	3.47
SiO_2		298.99	68.68	33.85	108.05	12.51	177.76		699.84	3.86
Al_2O_3		121.23	20.85	21.09	42.00	7.54	107.68		320.39	1.77
Fe	328.98	910.72	255.97	131.90	531.48	8.71	22.20		2,189.96	12.09
O_2		395.63	110.56	57.70	206.10	3.80	9.57	2,224.02	3,007.38	16.62
CaO		4.66	96.58	91.61	6.01	379.47	7.05		585.38	3.23
MgO		4.23	1.96	3.92	.98	264.29	4.23		279.61	1.54
P_2O_5		33.03	2.70	.92	.74	.12	1.10		38.61	.21
MnO		21.58	1.23	.61	.80	.37	.00		24.50	.14
K_2O		6.35	.54	2.61	3.03	.00	4.59		17.12	.09
Na_2O		6.34	.20	2.23	2.00	.00	1.48		12.25	.05
S		2.15	.00	.43	3.00	1.22	26.80		33.60	.19
CO_2		16.92	79.10	74.07	2.02	573.86	.00		745.97	4.12
C							2,110.66		2,110.66	11.65
H_2							12.08		12.08	.06
N_2								7,403.86	7,403.86	40.89
Total	328.98	2,117.84	646.89	437.92	1,000.95	1,253.11	2,626.85	9,695.80	18,108.34	
Per cent	1.82	11.69	3.57	2.43	5.53	6.92	14.50	53.54		100.00

Table 6.—*Composition of materials discharged, pounds per long ton of metal produced*

Constituent	Flue dust	Metal	Slag	Gas	Water	Total	Per cent
H_2O					559.12	559.12	3.09
SiO_2	34.48		569.26			603.74	3.33
Al_2O_3	18.70		301.69			320.39	1.77
Fe	92.47	2,084.25	13.24			2,189.96	12.10
O_2	39.67		1.89			41.56	.23
CaO	13.67		571.71			585.38	3.23
MgO	4.17		275.44			279.61	1.54
P_2O_5	.92		6.79			7.71	.04
MnO	1.29		2.44			3.73	.02
K_2O	5.62		11.50			20.83	.11
Na_2O	4.19		8.06			8.54	.05
S	8.16	.99	24.45			33.60	.19
CO_2	13.37			1,952.30		1,965.67	10.86
C	40.35	80.06				120.41	.66
Si		45.02				45.02	.25
Mn		16.17				16.17	.09
P		13.51				13.51	.076
H_2				19.88		19.88	.11
N_2				7,403.86		7,403.86	40.89
CO				3,868.85		3,868.85	21.37
Volatile matter	.80					.80	.004
Total	277.86	2,240.00	1,786.47	13,244.89	559.12	18,108.34	
Per cent	1.53	12.37	9.86	73.15	3.09		100.00

Table 7.—*Calculated analyses of materials discharged, per cent*

Constituent	Flue dust	Metal	Slag	Gas, per cent by weight	Gas, per cent by volume
SiO_2	12.41		31.86		
Al_2O_3	6.72		16.88		
Fe	33.30	93.021	.74		
O_2	14.30		.11		
CaO	4.93		32.01		
MgO	1.50		15.42		
P_2O_5	.33		.38		
MnO	.45		.14		
K_2O	2.02		.64		
Na_2O	1.51		.45		
S	2.94	.044	1.37		
CO_2	4.81			14.75	9.73
C	14.49	3.60			
Si		2.01			
Mn		.722			
P		.603			
H_2				.15	2.16
N_2				56.00	57.90
CO				29.15	30.30
Volatile matter	.29				
Total	100.00	100.00	100.00	100.00	100.00

TABLE 8.—*Actual analyses of materials discharged, per cent*

Constituent	Flue dust	Metal	Slag	Gas, by volume
SiO_2	12.9		32.15	
Al_2O_3	7.1		16.23	
Fe	34.2	93.021	[1] .28	
O_2	14.8		.13	
CaO	5.2		32.29	
MgO	1.6		15.88	
P_2O_5	.35		.33	
MnO	.49		.21	
K_2O	[2] 1.20		.64	
Na_2O	1.43		.45	
S	[3] .30	.044	1.41	
CO_2	5.06			9.78
C	15.07	3.60		
Si		2.01		
Mn		.722		
P		.603		
H_2	.30			2.17
N_2				58.01
CO				30.04
Volatile matter				
Total	100.00	100.00	100.00	100.00

[1] Analysis of slag made after removal of iron shot. Including shot, the slag contained 0.74 per cent Fe; 0.46 per cent of this was in the metallic form in shot, which is equal to approximately 82 pounds of iron per ton of metal.

[2] 2.29 pounds of K_2O and 0.23 pound of Na_2O carried to stoves and boilers; actual analysis of flue dust therefore lower than calculated analysis.

[3] Approximately 25 per cent of sulphur charged was volatilized, therefore not shown in actual analysis.

PRESENTATION OF DATA

ANALYSES OF GAS SAMPLES TAKEN IN THE INTERIOR OF THE STOCK

Tables 9 to 16 give the analyses of gas samples from the six planes. The samples have been arranged by date, time, and the distance from the inwall to the point of sampling; the constituents of the samples are reported in percentage by volume.

The results are presented in order, from the tuyère plane upward to the top of the furnace. Analyses of tuyère-gas samples, Table 9, are summarized only because the results found at the tuyère plane in this investigation compared favorably with those that had been published by Perrott and Kinney [12] for this and 12 other furnaces. Analyses of tuyère-gas samples taken during the course of this investigation have been plotted in Figure 7, and in Figure 8 are combined with the bureau's analyses of samples of tuyère gases in 12 other furnaces.

Analyses of samples taken on plane 5 are given in detail in Table 10 and are shown in the curves, Figure 9. Results of sampling on plane 4, which is 44 feet 1 inch below the stock line and 19 feet 3 inches above the tuyères, are shown in summary only, because the composition of the gas at this plane varied between narrow limits. Table 11 and Figure 10 give analyses. As analyses of gas samples

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[12] Perrott, G. St. J., and Kinney, S. P., "Combustion of coke in the blast-furnace hearth": Trans. Am. Inst. Min. and Met. Eng., vol. 69, 1923, pp. 543-584.

Kinney, S. P., "Combustion of coke at the tuyère level of the blast furnace": Blast Furnace and Steel Plant, vol. 13, June, 1925, pp. 243-247.

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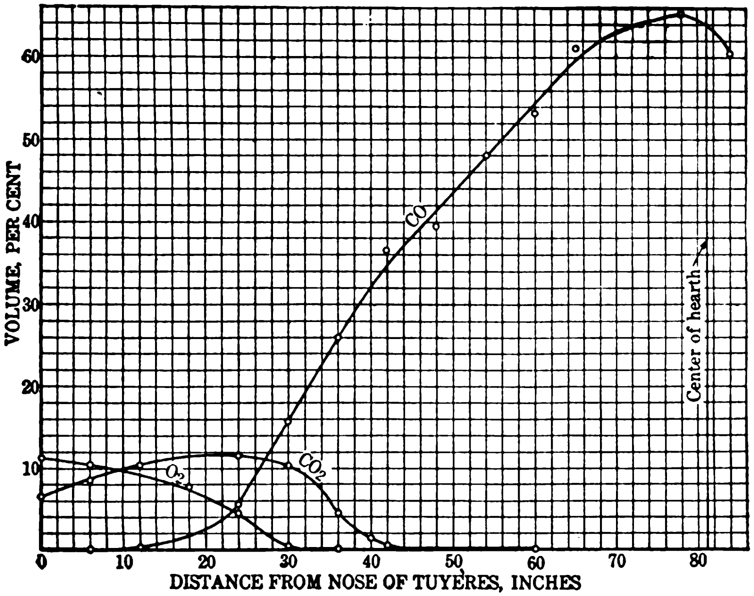

FIGURE 7.—Analyses of samples from tuyère plane

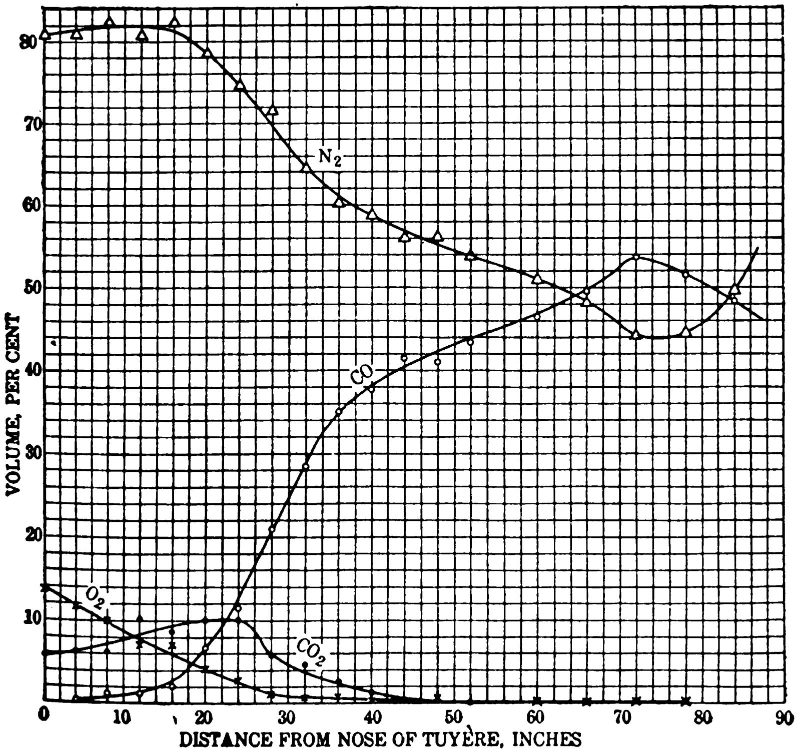

FIGURE 8.—Average analyses of samples from tuyère planes of 13 furnaces

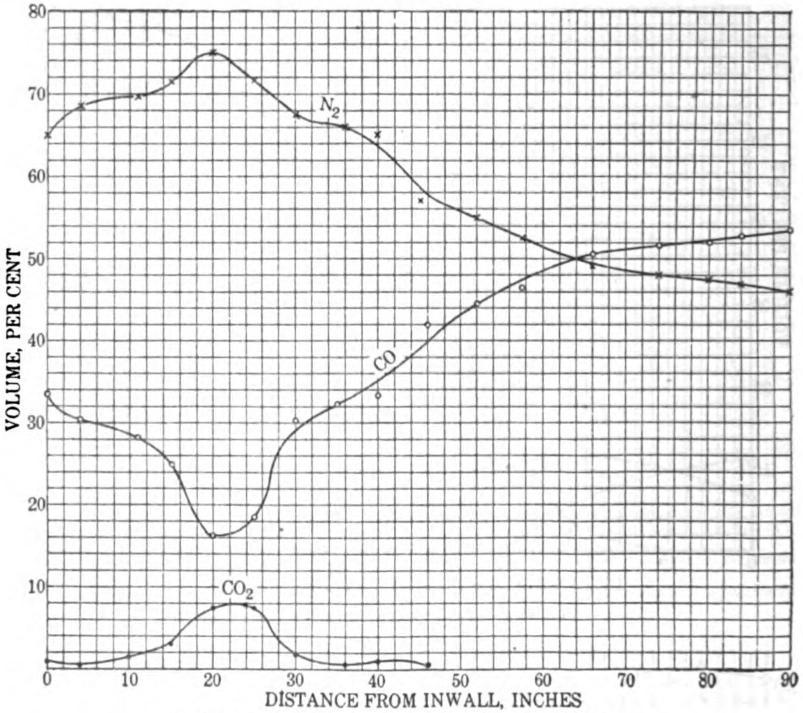

FIGURE 9.—Summary curves of gas analyses from plane 5

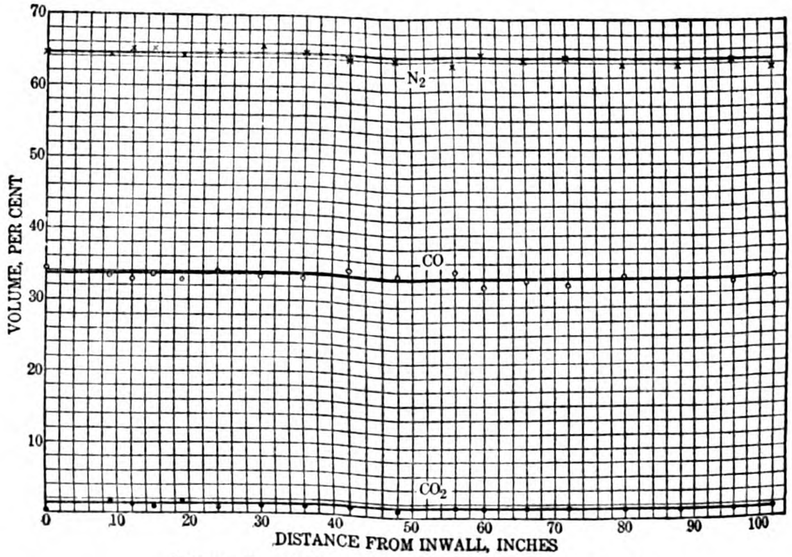

FIGURE 10.—Summary curves of gas analyses from plane 4

taken on planes 3, 2, and 1 are somewhat novel, they have been given in some detail in Tables 12, 13, and 14, and are plotted in Figures 11, 12, and 13, respectively. To show how the composition of the gas in one plane varied from day to day, analyses of gas samples from plane 3 for four days have been taken from Table 12 and plotted in Figures 14, 15, 16, and 17.

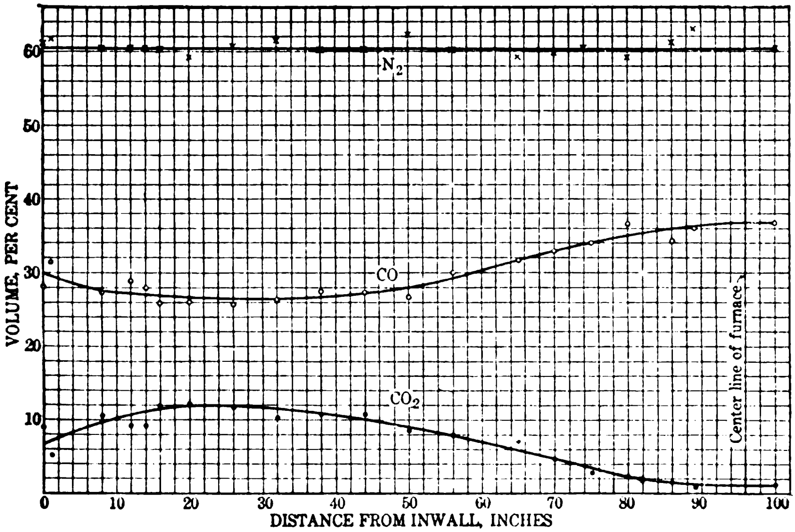

FIGURE 11.—Summary curves of gas analyses from plane 3

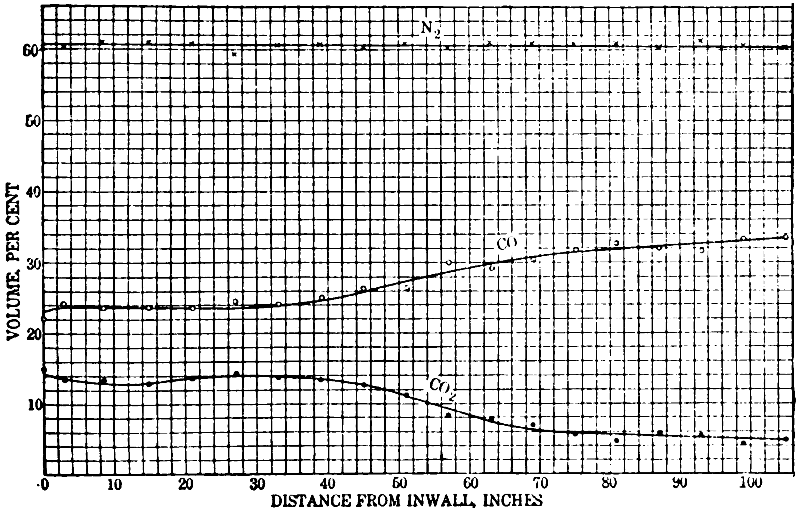

FIGURE 12.—Summary curves of gas analyses from plane 2

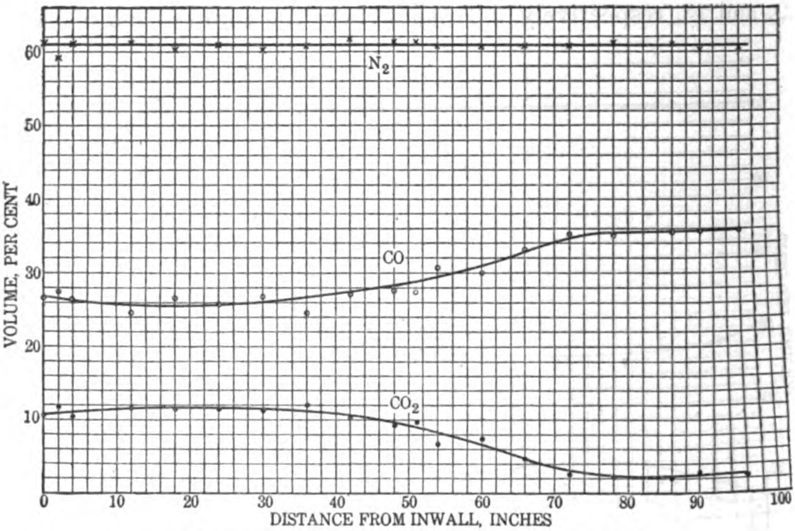

FIGURE 13.—Summary curves of gas analyses from plane 1

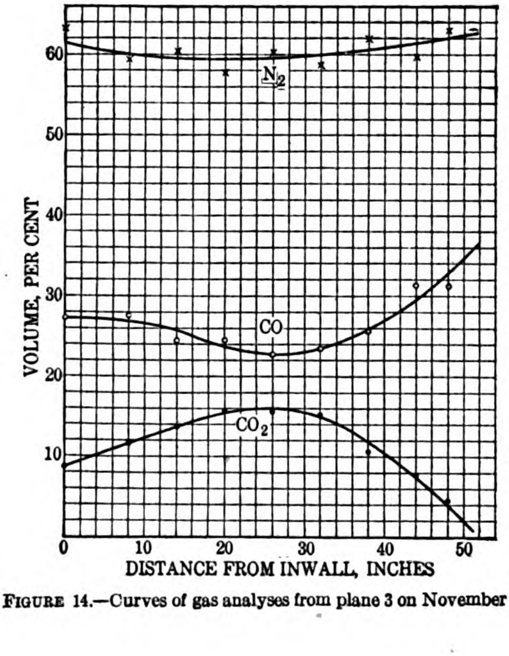

FIGURE 14.—Curves of gas analyses from plane 3 on November 2

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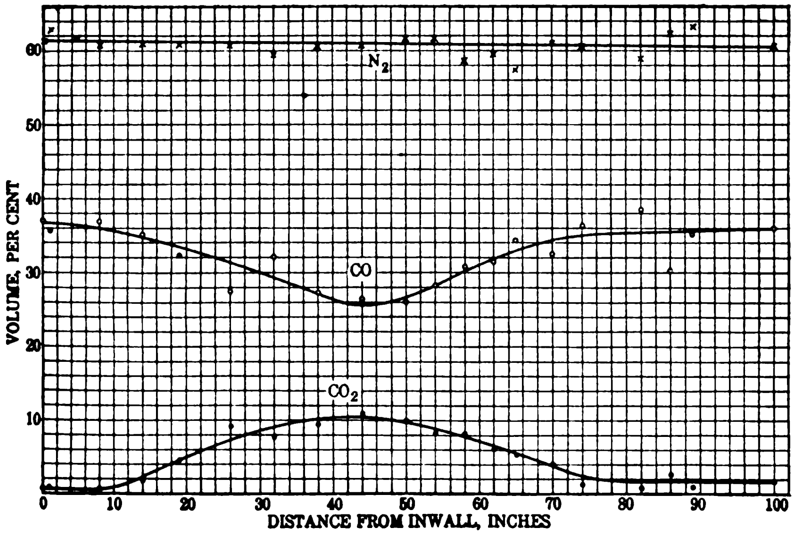

FIGURE 15.—Curves of gas analyses from plane 3 on November 6

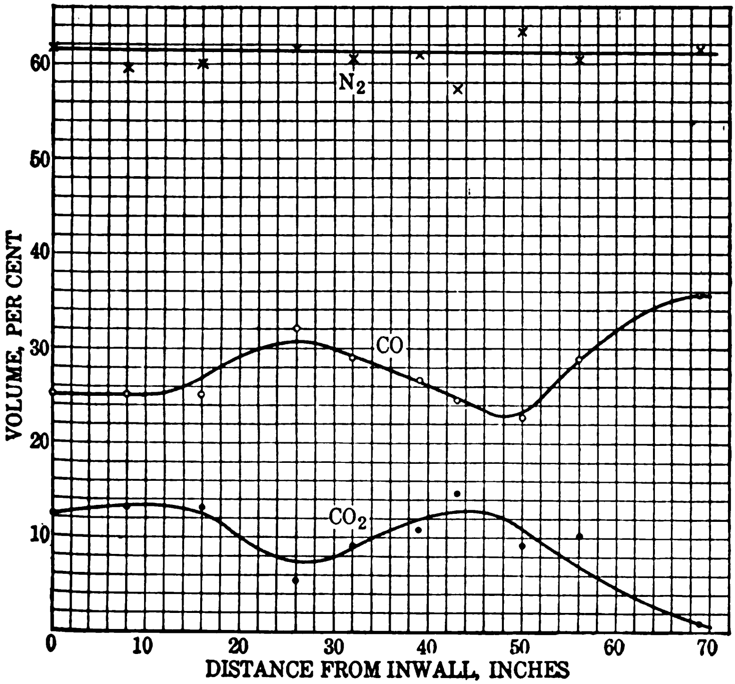

FIGURE 16.—Curves of gas analyses from plane 3 on November 8

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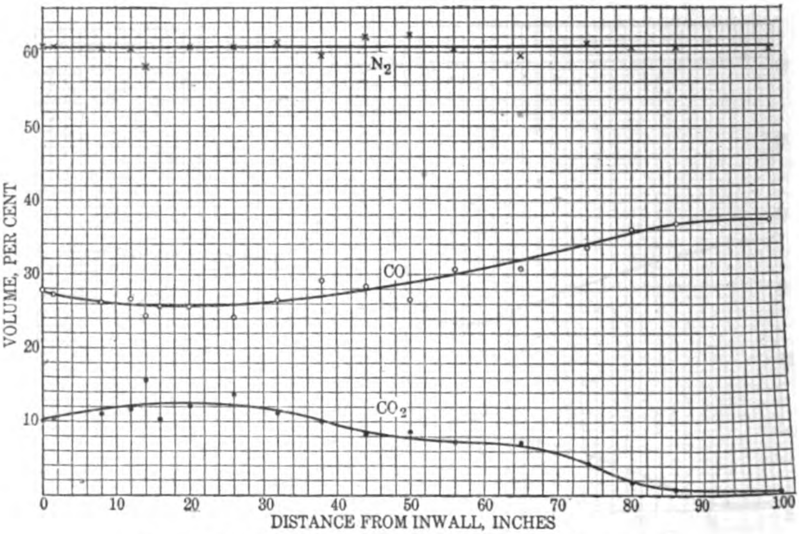

Figure 17.—Curves of gas analyses from plane 3 on November 10

Table 9.—*Summary of gas analyses on plane 6 or tuyère plane, 63 feet 4 inches below stock line*

Samples	Distance from nose of tuyère, inches	Per cent by volume				
		CO_2	O_2	CO	H_2	N_2
4	−6	0.0	20.7	0.0	0.0	79.3
5	0	5.5	11.2	.0	.0	83.3
5	6	8.6	10.6	.2	.0	80.6
4	12	10.4	9.0	.3	.0	80.3
5	18	11.1	7.8	.0	.0	81.1
4	24	12.2	4.6	2.1	1.2	79.9
4	30	10.4	.4	15.6	1.5	72.1
4	36	4.5	.2	26.3	2.1	66.9
5	42	.5	.0	36.8	1.8	60.9
5	48	.0	.0	39.9	2.1	58.0
4	54	.0	.0	48.2	2.0	49.8
5	60	.1	.0	53.3	1.8	44.8
5	65	.1	.0	61.2	1.9	36.8
5	78	.0	.0	66.3	1.9	31.8
6	84	.0	.0	60.8	2.0	37.2
70						
4	Top gas	10.7	.0	28.0	1.7	59.6

TABLE 10.[1]—*Analyses of gas samples from plane 5, 61 feet 1 inch below the stock line and 2 feet 3 inches above tuyère level*

Date	Time	Distance from inwall, inches	Per cent by volume				
			CO_2	O_2	CO	H_2	N_2
Jan. 3	11.10	0	0.8	0.0	32.8	0.8	65.6
3	11.12	0	1.4	.0	32.8	.9	65.4
3	11.13	0	1.2	.7	34.8	1.4	51.4
3	11.15	0	3.1	.3	32.0	.8	63.4
3	11.23	0	1.2	1.2	32.2	.8	64.6
3	11.30	0	1.0	.2	36.5	1.3	61.0
31	11.45	0	1.2	1.7	31.6	.9	64.6
31	11.46	0	.8	.0	35.2	.0	64.0
Feb. 11	12.07	0	.0	.0	36.3	.3	63.4
11	12.15	0	.5	.0	41.5	.4	57.4
11	12.25	0	.0	.0	34.5	1.3	64.2
11	12.26	0	.0	.0	33.5	1.5	64.0
11	12.28	0	1.4	.7	35.0	.4	62.5
11	12.40	0	.2	.0	30.2	.0	69.6
11	12.41	0	.0	.0	27.8	.5	71.7
12	12.40	0	.0	.0	32.2	.6	67.2
		Average	.8	.3	33.6	.7	64.6
Jan. 31	11.37	4	.6	1.7	32.6	.7	64.4
31	11.38	4	1.8	1.2	30.9	.7	65.4
Feb. 11	----------	4	.2	.0	23.1	.2	76.5
11	11.31	4	.7	.0	29.8	.2	69.3
11	11.34	4	.0	.0	31.7	.4	67.9
11	----------	4	.2	.0	27.0	.5	72.3
12	12.35	4	.3	.2	28.1	.0	71.4
12	12.36	4	.0	.0	27.9	.6	71.5
12	12.38	4	.0	.0	31.0	.2	68.8
14	12.30	4	.0	.2	29.3	.6	69.9
14	12.31	4	.0	.4	32.5	.7	66.4
14	12.32	4	.0	.0	33.6	.4	66.0
15	12.50	4	.2	.0	32.6	.3	66.9
15	12.51	4	.1	.0	34.7	.4	64.8
		Average	.3	.3	30.6	.4	68.4
Jan. 31	11.35	10	4.3	.8	25.5	.5	68.9
31	11.35	10	6.0	.3	23.0	.0	70.7
31	11.35	10	2.6	.2	28.2	1.0	67.9
31	11.36	10	2.4	.4	31.6	.0	65.6
Feb. 11	12.27	10	.0	.2	26.9	2.5	70.4
11	12.27	10	.2	.0	20.3	.6	78.1
11	12.31	10	.5	.0	31.6	.2	67.7
11	12.32	10	1.8	.0	28.6	.1	69.5
12	12.30	10	.4	.0	26.5	.0	73.0
12	12.32	10	.0	.2	29.0	.4	70.4
12	12.34	10	.3	.4	29.4	.3	69.9
14	12.34	10	.3	.0	30.1	.6	69.0
14	12.35	10	.0	.0	30.0	.5	69.5
14	12.35	10	.7	.0	31.0	.4	62.1
16	12.46	10	.9	.1	30.0	.3	68.8
16	12.47	10	1.2	.0	28.1	.2	70.5
		Average	1.4	.1	28.1	.5	69.9
Jan. 31	11.32	15	6.7	.2	32.9	.5	69.7
31	11.33	15	6.7	.5	20.4	.1	71.7
31	11.33	15	7.1	.0	22.8	.0	70.1
Feb. 11	12.21	15	2.5	.0	27.7	.0	69.8
11	12.22	15	4.2	.0	23.5	.3	72.0
11	12.22	15	.0	.2	27.7	.2	71.9
11	12.25	15	2.5	.0	26.9	.7	69.9
12	12.27	15	2.1	.0	27.9	.7	69.3
12	12.28	15	3.2	.0	28.5	.2	68.1
12	12.29	15	2.0	.0	27.6	.3	70.0
14	12.26	15	2.1	.2	28.0	.4	69.3
14	12.27	15	1.6	.3	27.2	.6	70.3
14	12.27	15	1.8	.2	27.0	.6	70.4
16	12.43	15	3.0	.0	26.2	.5	70.3
16	12.44	15	3.2	.2	25.9	.4	70.3
		Average	3.0	.1	25.0	.4	71.5

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[1] Samples for October, November, and December in Tables 10 to 14 were taken in 1923, those for January and February in 1924. Time recorded between 8 and 12 indicates a. m., 12.01 and 5, p. m.

TABLE 10.—*Analyses of gas samples from plane 5, 61 feet 1 inch below the stock line and 2 feet 3 inches above tuyère level*—Continued

Date	Time	Distance from inwall, inches	Per cent by volume				
			CO_2	O_2	CO	H_2	N_2
Feb. 11	12.17	20	11.7	0.2	11.7	0.3	76.0
11	12.18	20	1.2	.0	9.3	.0	[1] 10.5
14	12.20	20	8.0	.0	18.0	.4	73.6
14	12.21	20	8.6	.0	17.0	.6	73.8
14	12.21	20	9.0	.1	17.6	.8	72.5
16	12.38	20	8.0	.0	20.0	.9	71.1
16	12.37	20	8.1	.0	21.0	.6	71.3
		Average	7.8	.1	16.3	.5	75.3
Jan. 31	11.25	25	6.6	.0	17.8	2.1	63.5
31	11.25	25	12.1	.9	12.6	.1	74.3
31	11.26	25	8.4	.7	17.5	.8	72.6
31	11.30	25	15.8	.0	3.4	.0	[1] 80.8
Feb. 11	12.19	25	1.2	.2	10.7	.5	67.4
12	12.17	25	8.0	1.0	16.7	.3	74.0
14	12.19	25	10.0	.3	16.6	.6	72.5
16	12.35	25	6.0	.4	18.2	.7	74.7
		Average	7.5	.4	18.6	.7	72.8
Feb. 11	12.09	30	1.7	.4	30.4	.2	67.3
11	12.10	30	2.1	.0	29.4	.0	68.3
14	12.14	30	2.5	.0	31.0	.3	66.2
14	12.15	30	1.3	.0	29.6	.4	67.7
16	12.30	30	2.0	.0	30.4	.6	67.0
16	12.31	30	2.0	.1	30.6	.3	67.0
		Average	1.9	.1	30.2	.3	67.5
Feb. 11	12.04	36	.0	.2	34.1	.5	64.2
11	12.05	36	1.7	.2	32.6	.5	65.2
11	12.06	36	.2	.7	31.5	.0	67.6
14	12.10	36	.6	.3	33.0	.0	66.1
14	12.11	36	.0	.4	32.6	.0	67.0
16	12.25	36	.0	.3	34.2	.2	65.3
16	12.26	36	.0	.6	33.5	.0	65.8
		Average	.3	.3	32.9	.1	66.4
Jan. 31	11.16	40	.5	.0	32.6	.8	66.1
31	11.66½	40	.5	.2	33.0	.7	65.6
31	11.17	40	.2	.5	41.3	.0	58.0
31	11.18	40	.5	.8	34.2	.6	63.9
31	11.19	40	.7	.0	32.6	.0	66.7
31	11.24	40	.0	.0	33.6	1.0	65.3
Feb. 12		40	.7	.2	31.8	.5	66.8
12	11.59	40	2.5	.4	32.1	.7	64.3
12	12.04	40	1.2	.2	33.7	.3	64.6
12		40	.5	.7	30.9	.0	67.9
16	12.20	40	.2	.2	33.6	.5	65.5
16		40	.4	.3	32.7	.6	66.0
		Average	.7	.3	33.4	.5	65.1
Feb. 11	12.00	46	.0	.2	42.0	.3	59.5
11	12.02	46	.2	.0	40.0	.6	59.2
12	12.15	46	.3	.1	44.0	.7	54.9
14	12.00	46	.4	.0	43.7	.5	55.4
16	12.08	46	.0	.0	40.6	.7	58.7
16	12.09	46	.2	.0	42.0	.0	57.8
16	12.09	46	.1	.0	43.0	.4	56.5
16	12.10	46	.1	.0	40.9	.6	58.4
		Average	.2	.1	42.2	.4	57.0
Feb. 11	11.40	52	.1	.0	44.1	.6	55.9
11	11.41	52	.0	.1	44.0	.8	56.1
11	11.42	52	.0	.0	49.2	.5	50.3
12	12.08	52	.0	.0	43.7	.1	54.2
12	12.09	52	.0	.0	44.4	.0	55.6
12	12.09	52	.2	.0	44.9	.0	54.9
14	11.41	52	.0	.0	40.9	.9	58.2
14	11.42	52	.0	.0	50.6	.0	49.4
16	11.58	52	.0	.0	49.2	1.0	49.8
16	11.59	52	.0	.0	44.0	.3	55.7
16	12.00	52	.0	.1	46.0	.6	53.4
16	12.03	52	.0	.0	42.0	.7	57.3
		Average	.0	.0	44.5	.5	55.0

[1] Not in average.

TABLE 10.—*Analyses of gas samples from plane 5, 61 feet 1 inch below the stock line and 2 feet 3 inches above tuyère level*—Continued

Date	Time	Distance from inwall, inches	Per cent by volume				
			CO_2	O_2	CO	H_2	N_2
Feb. 11	11.30	58	0.0	0.0	47.5	0.7	51.8
11	11.31	58	.1	.0	49.0	.9	50.0
11	11.33	58	.0	.0	45.2	1.1	53.7
11	11.35	58	.0	.0	45.6	.9	53.5
12	12.00	58	.2	.0	46.9	.0	52.9
12	12.01	58	.0	.2	50.0	.7	49.1
12	12.02	58	.0	.0	46.0	.9	53.1
12	12.03	58	.0	.0	46.6	.6	52.7
12	12.04	58	.0	.0	49.2	.4	50.4
16	11.40	58	.0	.0	47.0	.0	53.0
16	11.43	58	.0	.2	47.3	.2	52.5
16	11.45	58	.0	.0	45.9	.9	52.2
		Average	.0	.0	46.8	.6	52.6
Feb. 11	11.20	66	.0	.0	50.1	.9	49.0
11	11.21	66	.0	.1	50.2	.4	49.3
11	11.22	66	.0	.0	49.1	.6	50.3
11	11.23	66	.0	.0	48.9	.7	49.6
11	11.24	66	.0	.2	52.0	.9	46.9
11	11.20	66	.0	.0	51.3	.0	48.7
12	11.41	66	.1	.0	40.1	.9	48.9
12	11.41	66	.2	.0	52.1	.9	46.8
12	11.42	66	.0	.0	50.9	.9	48.2
12	11.45	66	.0	.0	50.0	.7	49.3
12	11.46	66	.0	.2	48.9	.0	50.9
14	11.30	66	.0	.0	50.6	1.0	48.4
14	11.31	66	.0	.0	49.3	1.1	49.6
14	11.32	66	.0	.6	52.6	.7	46.0
14	11.33	66	.0	.0	50.9	.6	48.5
16	11.38	66	.0	.1	59.0	.9	40.1
		Average	.0	.0	50.4	.6	49.0
Feb. 11	11.05	74	.0	.0	52.0	.8	47.2
11	11.06	74	.0	.1	58.0	.6	41.3
11	11.07	74	.0	.0	48.0	.9	51.1
11	11.09	74	.0	.0	49.6	.9	50.5
11	11.12	74	.0	.0	49.3	.0	50.7
12	11.29	74	.0	.0	53.6	1.0	45.4
12	11.32	74	.0	.1	50.9	.9	48.1
12	11.35	74	.0	.0	52.7	.7	44.6
12	11.36	74	.0	.2	51.6	.6	47.5
12	11.37	74	.2	.1	50.9	.5	51.7
14	11.10	74	.1	.0	52.0	.0	47.9
14	11.11	74	.0	.0	54.0	.4	45.6
14	----------	74	.0	.0	52.0	.7	47.3
14	11.14	74	.0	.0	51.9	.6	47.5
16	11.36	74	.0	.0	48.0	.9	51.5
		Average	.0	.0	51.6	.5	47.9
Feb. 11	10.55	80	.0	.0	52.5	.6	46.9
11	10.56	80	.0	.2	51.0	.9	48.1
11	10.59	80	.0	.0	52.0	.7	57.7
12	11.15	80	.0	.0	53.0	.0	47.0
12	11.16	80	.1	.0	49.6	.7	49.6
12	11.17	80	.0	.0	49.9	.9	50.8
12	11.18	80	.2	.0	51.8	.8	47.2
14	11.00	80	.0	.0	52.7	.1	47.2
14	11.01	80	.0	.0	53.0	.9	46.1
16	11.34	80	.0	.1	54.0	.7	45.2
16	----------	80	.0	.2	51.1	.6	48.1
		Average	.0	.0	52.0	.7	47.3
Feb. 11	10.46	84	.1	.0	53.0	.9	46.0
11	10.47	84	.0	.0	53.6	.8	45.6
11	10.48	84	.0	.1	56.4	.7	42.8
11	10.49	84	.2	.0	48.2	.6	51.0
12	11.11	84	.1	.0	51.2	.0	48.7
12	11.12	84	.1	.0	53.6	.1	46.2
12	11.12	84	.0	.0	51.4	.9	47.7
12	11.13	84	.0	.0	40.6	.8	58.6
12	----------	84	.0	.0	53.0	.8	46.2
12	11.14	84	.0	.0	53.9	.9	45.2
14	10.50	84	.1	.0	51.0	.8	48.1
14	10.51	84	.0	.0	60.2	.9	38.9
14	10.52	84	.0	.1	53.0	.8	46.2

TABLE 10.—*Analyses of gas samples from plane 5, 61 feet 1 inch below the stock line and 2 feet 3 inches above tuyère level*—Continued

Date	Time	Distance from inwall, inches	Per cent by volume				
			CO_2	O_2	CO	H_2	N_2
Feb. 14	10.53	84	0.0	0.0	53.7	0.0	46.3
14	10.53	84	.0	.0	54.2	.1	45.7
16	11.30	84	.0	.0	51.6	.9	47.5
16	11.31	84	.0	.0	53.2	.8	46.0
16	11.32	84	.0	.1	54.0	.8	45.1
16	11.33	84	.1	.0	53.0	.9	46.0
16	11.33	84	.0	.0	53.4	.9	45.7
		Average	.0	.0	52.6	.7	46.7
Feb. 12	10.55	90	.0	.0	53.0	.7	46.3
12	10.56	90	.0	.1	50.6	.8	48.5
12	10.57	90	.1	.0	57.2	.8	58.1
12	10.59	90	.0	.0	56.3	.6	43.1
16	11.20	90	.0	.0	53.0	.9	46.1
16	11.21	90	.0	.0	51.6	.9	47.5
16	11.22	90	.0	.0	53.0	.8	46.2
16	11.24	90	.1	.0	53.0	.0	46.9
16	11.27	90	.1	.0	50.9	.0	48.1
16	11.29	90	.2	.2	53.0	.8	46.0
		Average	.0	.0	53.6	.7	45.7

ANALYSIS OF TOP GAS

Date	Time	Distance from inwall, inches	CO_2	O_2	CO	H_2	N_2
Jan. 3	10.00	Top	9.0	0.0	30.6	1.4	58.2
3	2.00	do	9.8	.0	29.6	2.2	58.4
31	10.30	do	10.5	.0	27.6	3.3	58.6
31	1.40	do	10.4	.0	29.4	1.5	58.7
Feb. 11	9.40	do	10.8	.0	27.6	1.2	61.9
11	1.50	do	10.4	.0	29.4	1.6	58.6
12	9.00	do	9.3	.0	27.6	1.2	61.9
12	2.00	do	9.3	.0	28.1	1.6	61.0
14	10.05	do	9.2	.0	27.3	1.9	61.3
14	1.50	do	10.0	.0	28.4	2.4	59.2
16	9.00	do	10.6	.0	26.0	1.9	62.3
		Average	10.0	.0	28.3	1.8	60.0

TABLE 11.—*Summary of gas analyses on plane 4, 44 feet 1 inch below stock line and 19 feet 3 inches above tuyères*

Samples	Distance from inwall, inches	Per cent by volume				
		CO_2	O_2	CO	H_2	N_2
15	0	0.3	0.0	34.4	0.7	64.6
8	6	1.5	.0	33.2	1.1	64.2
12	12	1.2	.0	32.8	.7	65.3
2	15	.7	.0	33.4	.5	65.4
16	18	1.7	.0	32.9	1.1	64.3
10	24	.5	.0	34.0	.8	64.7
6	30	1.0	.0	32.9	.7	65.4
7	36	1.0	.0	33.1	.9	64.9
8	42	1.0	.0	34.4	.6	64.0
6	48	.8	.0	34.2	.9	64.1
6	56	1.1	.0	34.7	.6	63.6
8	60	1.2	.0	32.9	.9	65.0
4	66	1.2	.0	33.8	.9	64.1
4	72	1.3	.0	33.0	.9	64.8
6	80	1.1	.0	34.1	1.1	63.7
6	88	1.3	.0	33.7	1.2	63.8
7	96	1.1	.0	33.3	1.2	64.4
4	102	1.3	.0	34.3	.9	63.5
4	110	.8	.0	33.8	1.0	64.4
139	Average	1.1	.0	33.6	.8	64.5
5	Top gas (average)	10.9	.0	26.4	1.8	60.9
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Table 12.—*Analyses of gas samples on plane 3, 21 feet 7 inches below stock line and 41 feet 9 inches above tuyères*

Date	Time	Distance from inwall, inches	Per cent by volume				
			CO_2	O_2	CO	H_2	N_2
Oct. 13	1.15	0	11.8	--------	24.4	6.2	57.6
19	2.00	0	14.2	--------	25.9	1.9	58.0
19	2.00	0	12.9	--------	25.3	2.5	59.3
27	10.00	0	.0	--------	35.4	.9	63.7
27	10.05	0	.0	--------	35.0	4.9	60.1
Nov. 2	2.00	0	9.0	--------	29.7	.8	60.5
2	2.02	0	8.6	--------	28.0	--------	--------
2	2.36	0	8.7	--------	24.3	.6	66.4
6	10.00	0	.3	--------	36.8	1.6	61.3
8	11.03	0	12.3	--------	26.0	1.1	60.6
8	11.05	0	12.3	--------	24.4	1.5	61.8
8	11.08	0	11.6	--------	25.3	1.1	62.0
8	11.17	0	12.0	--------	25.2	1.2	61.6
10	10.01	0	8.7	--------	24.3	.6	66.4
10	10.28	0	11.1	--------	27.2	1.6	60.1
10	10.37	0	7.7	--------	31.4	1.2	59.7
10	10.51	0	9.2	--------	28.8	1.3	60.7
10	10.56	0	12.1	--------	26.2	1.1	60.6
		Average	9.0	--------	28.0	1.8	61.2
Nov. 6	10.07	2	.9	--------	35.6	2.0	61.5
6	10.45	2	.7	--------	34.2	1.0	63.4
6	10.46	2	.2	--------	36.0	.8	63.5
8	10.02	2	9.9	--------	28.6	1.7	59.8
10	10.03	2	11.6	--------	26.4	1.5	60.5
10	10.53	2	9.2	--------	28.2	1.3	61.3
		Average	5.4	--------	31.5	1.3	61.8
Nov. 2	2.07	8	13.5	--------	27.6	.4	58.3
2	2.55	8	10.4	--------	28.5	1.0	60.1
6	10.14	8	.4	--------	37.0	1.7	60.9
8	11.04	8	13.3	--------	25.2	1.7	59.8
10	10.04	8	11.7	--------	26.0	1.5	60.8
10	10.05	8	11.6	--------	26.4	1.5	60.5
10	10.53	8	10.8	--------	26.6	3.2	59.4
10	10.54	8	15.5	--------	23.2	2.6	58.7
10	10.55	8	9.3	--------	26.6	1.9	62.2
10	10.56	8	14.0	--------	23.8	.6	61.6
10	10.57	8	7.7	--------	31.4	1.2	59.7
		Average	10.7	--------	27.5	1.6	60.2
Oct. 27	2.27	12	1.1	--------	36.2	.9	59.8
27	2.45	12	.9	--------	38.8	.7	59.6
27	2.48	12	.1	--------	27.8	1.0	61.1
Nov. 10	10.06	12	12.5	--------	23.8	1.6	61.1
10	10.07	12	11.4	--------	27.3	1.4	59.7
10	10.08	12	11.8	--------	24.3	1.6	62.3
10	10.09	12	11.2	--------	25.2	1.1	62.5
10	10.58	12	12.4	--------	24.6	1.4	61.6
10	10.59	12	11.9	--------	27.2	2.5	58.4
10	11.00	12	8.6	--------	30.8	2.3	58.3
10	11.01	12	10.0	--------	27.0	2.0	61.0
10	11.02	12	13.0	--------	25.8	2.1	59.1
10	11.03	12	14.2	--------	22.6	2.9	60.3
		Average	9.2	--------	28.7	1.7	60.3
Nov. 6	10.44	13	2.7	--------	34.4	2.0	60.9
6	10.45	13	1.0	--------	36.0	1.5	61.5
2	2.08	14	11.1	--------	21.3	1.8	65.8
2	2.10	14	15.3	--------	25.2	.8	58.7
2	2.35	14	13.1	--------	26.2	1.2	59.5
6	10.11	14	1.8	--------	36.0	1.7	60.5
6	10.18	14	2.2	--------	34.5	1.9	61.4
8	10.22	14	13.8	--------	24.0	1.0	61.2
10	10.08	14	15.4	--------	26.4	2.1	56.1
10	10.12	14	16.4	--------	21.8	2.0	58.9
		Average	9.3	--------	28.6	1.6	60.5
Nov. 2	2.12	16	15.2	--------	21.3	1.4	59.1
8	11.25	16	13.2	--------	25.2	2.0	59.6
8	11.27	16	12.4	--------	26.8	.8	60.0
10	10.13	16	11.4	--------	27.5	1.4	59.7
10	10.14	16	10.6	--------	27.0	1.4	61.0
10	11.04	16	9.3	--------	24.9	3.5	62.3
		Average	12.0	--------	26.0	1.8	60.2

Table 12.—*Analyses of gas samples on plane 3, 21 feet 7 inches below stock line and 41 feet 9 inches above tuyères*—Continued

Date	Time	Distance from inwall, inches	Per cent by volume				
			CO_2	O_2	CO	H_2	N_2
Nov. 2	2.13	20	16.8	----------	28.4	1.3	53.5
2	2.33	20	15.1	----------	19.7	2.9	62.3
6	10.42	19	4.9	----------	32.4	2.0	60.7
10	10.16	20	12.3	----------	26.0	1.1	60.6
10	10.18	20	13.0	----------	25.8	1.4	59.8
10	11.06	20	11.6	----------	25.3	1.1	62.0
		Average	12.3	----------	26.2	1.6	59.9
Nov. 2	2.31	25	14.0	----------	22.2	.5	62.8
2	2.14	26	17.7	----------	23.2	1.4	57.7
6	10.19	26	14.0	----------	22.7	1.8	61.5
6	10.45	26	4.6	----------	31.9	2.1	61.4
8	11.27	26	5.5	----------	32.1	1.8	60.4
10	10.19	26	13.8	----------	24.0	1.0	61.2
10	11.07	26	14.1	----------	24.2	1.4	60.3
		Average	11.9	----------	25.8	1.4	60.9
Nov. 2	2.29	32	16.1	----------	23.7	1.6	58.5
6	10.20	32	4.8	----------	32.6	1.8	60.8
6	10.41	32	7.3	----------	31.9	2.0	58.8
8	11.30	32	9.0	----------	29.4	.9	60.7
10	10.21	32	10.6	----------	28.2	1.3	59.9
10	10.22	32	12.0	----------	23.4	1.4	63.2
10	11.09	32	10.6	----------	28.4	1.4	59.6
		Average	10.1	----------	26.8	1.5	61.6
Oct. 27	2.52	38	11.3	----------	28.6	2.2	57.9
27	2.54	38	12.1	----------	29.3	1.6	57.0
Nov. 2	2.14	38	5.3	----------	24.0	1.7	69.0
2	2.16	38	12.7	----------	27.8	.9	58.6
2	2.27	38	14.5	----------	25.8	1.1	58.6
6	10.21	38	7.8	----------	28.5	1.5	63.2
6	10.40	38	11.9	----------	27.2	2.3	58.6
8	11.36	38	10.6	----------	27.0	1.4	61.0
10	10.23	38	10.4	----------	29.0	1.0	59.6
10	11.10	38	9.8	----------	29.1	1.3	59.8
		Average	10.6	----------	27.6	1.5	60.3
Nov. 2	2.17	44	7.8	----------	31.5	.9	59.8
6	10.21	44	11.5	----------	27.0	2.1	59.4
6	10.21	44	11.5	----------	26.2	1.7	60.6
6	10.22	44	10.0	----------	27.0	2.0	61.0
8	11.32	44	15.0	----------	23.8	2.0	59.2
8	11.33	44	16.3	----------	25.2	1.7	56.8
10	10.28	44	8.0	----------	28.9	1.6	61.5
10	10.29	44	8.2	----------	30.2	1.5	60.1
10	11.12	44	9.3	----------	26.6	1.9	62.2
		Average	10.8	----------	27.4	1.7	60.1
Nov. 2	2.22	48	4.8	----------	31.4	.9	62.9
6	10.29	50	10.4	----------	26.1	1.7	61.8
10	11.34	50	9.3	----------	22.9	4.5	63.3
10	10.30	50	7.9	----------	29.6	2.0	60.5
10	10.31	50	9.3	----------	26.0	2.2	62.5
10	11.13	50	8.8	----------	27.4	1.6	62.2
10	11.34	50	9.3	----------	22.9	4.5	63.3
		Average	8.5	----------	26.6	2.5	62.4
Nov. 6	10.22	54	8.2	----------	28.4	1.6	61.8
6	10.36	58	8.6	----------	30.8	2.3	58.3
8	11.35	56	10.4	----------	29.0	.2	60.4
10	10.32	56	7.6	----------	31.0	1.7	59.7
10	10.33	56	7.1	----------	31.0	1.5	60.4
10	11.14	56	7.7	----------	29.0	1.9	61.4
10	11.15	56	7.0	----------	31.2	2.0	59.8
		Average	8.1	----------	30.2	1.6	60.1

TABLE 12.—*Analyses of gas samples on plane 3, 21 feet 7 inches below stock line and 41 feet 9 inches above tuyères*—Continued

Date	Time	Distance from inwall, inches	Per cent by volume				
			CO_2	O_2	CO	H_2	N_2
Nov. 6	10.24	62	6.5	----------	31.8	2.0	59.7
6	10.25	65	5.5	----------	34.8	2.4	57.3
10	10.34	65	6.6	----------	31.4	1.8	60.2
10	10.35	65	6.9	----------	34.0	1.9	57.2
10	11.16	65	7.9	----------	29.6	2.0	60.5
10	11.17	65	9.6	----------	28.6	1.9	59.9
		Average	7.2	----------	31.7	2.0	59.1
Oct. 27	3.22	70	8.1	----------	31.0	2.7	58.2
Nov. 6	10.24	70	4.8	----------	35.6	1.6	58.5
6	10.26	68	3.4	----------	32.9	2.1	61.6
8	11.31	69	1.4	----------	35.6	1.6	61.4
10	10.36	68	6.1	----------	31.6	2.1	60.2
10	10.37	68	4.2	----------	33.6	1.7	60.5
10	11.18	68	6.0	----------	32.2	2.0	59.8
		Average	4.9	----------	33.2	2.0	59.9
Oct. 27	3.22	73	1.1	----------	37.8	1.4	59.6
27	3.23	73	2.2	----------	29.6	6.4	61.8
Nov. 6	10.35	74	1.4	----------	36.2	1.9	60.5
6	10.54	74	.7	----------	38.6	1.8	58.9
8	10.36	74	5.7	----------	32.9	1.0	60.4
10	10.38	74	2.5	----------	34.0	1.9	61.6
10	10.39	74	4.2	----------	33.6	1.7	60.5
10	11.40	74	5.9	----------	31.0	1.5	61.6
		Average	3.0	----------	34.1	2.2	60.7
Oct. 27	3.05	79	3.2	----------	37.4	3.2	56.2
27	3.07	79	2.4	----------	37.4	1.5	58.7
Nov. 6	----------	81	.7	----------	38.6	1.8	58.9
8	11.37	80	4.5	----------	35.0	1.4	59.1
10	10.41	80	2.8	----------	35.4	1.3	60.5
10	10.42	80	2.4	----------	35.6	2.2	59.8
10	11.18	80	.5	----------	37.0	1.7	60.8
		Average	2.4	----------	36.7	1.9	59.2
Nov. 6	10.31	86	2.6	----------	33.6	3.4	60.4
6	10.32	86	2.8	----------	27.1	5.9	64.2
10	10.43	86	1.0	----------	37.2	2.5	59.3
10	10.45	86	.9	----------	35.6	2.0	61.5
10	11.20	86	.4	----------	37.0	1.7	60.9
		Average	1.5	----------	34.1	3.1	61.3
Nov. 6	----------	89	.5	----------	35.2	.5	63.4
Nov. 6	10.29	100	2.4	----------	35.6	2.2	59.8
6	10.30	100	1.1	----------	36.6	1.3	61.0
10	10.48	100	.9	----------	36.9	1.6	60.6
10	10.21	100	.5	----------	38.0	1.6	59.9
		Average	1.2	----------	36.8	1.7	60.4

ANALYSES OF TOP GAS

Date	Time	Distance from inwall, inches	CO_2	O_2	CO	H_2	N_2
Oct. 13	9.35	----------	13.3	----------	24.9	4.2	57.6
19	2.25	----------	10.6	----------	26.0	1.9	61.5
27	10.20	----------	7.3	----------	32.7	1.4	58.6
Nov. 2	1.00	----------	9.3	----------	30.6	1.4	58.7
2	3.40	----------	10.4	----------	29.4	1.5	58.7
6	10.55	----------	9.2	----------	31.8	1.2	57.8
6	3.45	----------	9.6	----------	25.4	2.6	62.4
8	9.00	----------	10.8	----------	26.2	1.8	61.2
8	9.40	----------	10.9	----------	24.8	3.8	60.5
10	9.00	----------	8.1	----------	30.8	1.9	59.2
		Average	9.0	----------	28.3	2.2	60.5

TABLE 13.—*Analyses of gas samples on plane 2, 10 feet below stock line, and 53 feet 4 inches above tuyère level*

Date	Time	Distance from inwall, inches	Per cent by volume				
			CO_2	O_2	CO	H_2	N_2
Nov. 9	10.34	0	18.3	0.0	20.7	2.6	58.4
9	10.37	0	10.9	.0	20.2	1.8	66.6
9	10.37	0	14.2	.0	22.6	2.9	60.3
9	10.38	0	14.2	.0	23.6	2.1	60.1
9	10.40	0	14.0	.0	24.5	2.2	59.3
9	11.05	0	19.2	.0	18.6	2.2	60.0
9	11.06	0	19.1	.0	19.3	3.9	57.7
9	11.06	0	17.2	.0	20.7	2.0	60.1
9	11.07	0	19.3	.0	19.1	2.9	58.7
9	11.08	0	17.5	.0	20.4	2.2	59.9
13	11.35	0	12.2	.0	24.4	.6	62.8
13	12.09	0	11.8	.0	24.3	1.6	62.3
13	12.10	0	11.5	.0	25.3	1.6	61.6
15	11.20	0	11.2	.0	26.4	1.4	61.0
15	11.21	0	11.3	.0	25.9	1.3	61.5
15	12.04	0	17.6	.0	20.3	1.7	60.4
15	12.07	0	17.1	.0	20.9	1.5	60.5
		Average	15.1	.0	22.2	2.1	60.6
Nov. 9	10.33	3	13.5	.0	24.2	2.1	60.2
9	----	3	15.2	.0	22.9	2.5	59.4
9	11.04	3	17.9	.0	20.4	3.2	58.5
13	11.36	3	12.5	.0	23.3	.8	63.4
13	12.08	3	12.1	.0	24.4	1.5	62.0
15	12.24	3	10.2	.0	27.4	1.3	61.1
15	12.06	3	10.8	.0	26.6	3.2	59.4
15	12.07	3	11.7	.0	26.0	1.5	60.8
		Average	13.0	.0	24.4	2.0	60.6
Nov. 9	10.42	10	16.1	.0	22.2	2.1	59.6
9	10.43	10	16.4	.0	21.8	2.0	59.8
13	12.07	9	12.1	.0	26.8	1.3	60.4
13	11.56	9	12.6	.0	23.8	----	----
13	12.08	9	12.1	.0	25.4	1.4	61.1
15	11.20	9	9.3	.0	26.6	1.9	62.2
15	11.24	9	13.8	.0	21.1	2.7	62.4
		Average	13.2	.0	23.9	1.9	61.0
Nov. 9	10.28	15	14.6	.0	23.6	1.9	59.9
9	10.24	17	14.6	.0	24.0	2.4	59.9
13	11.47	15	13.2	.0	23.4	1.4	62.0
13	11.51	15	12.9	.0	21.2	1.5	64.4
13	12.06	15	12.4	.0	24.6	1.5	61.5
13	12.06	15	11.9	.0	25.2	1.5	61.4
15	11.24	15	14.2	.0	23.6	1.6	60.6
15	11.25	15	14.5	.0	22.8	2.0	60.7
15	12.03	15	12.5	.0	25.8	2.4	59.3
		Average	13.4	.0	23.8	1.8	61.0
Nov. 9	10.10	18	16.9	.0	21.0	2.0	60.1
9	10.46	20	14.6	.0	24.2	1.5	59.7
13	11.39	21	13.6	.0	22.8	1.8	61.8
13	11.40	21	12.0	.0	23.8	1.4	62.8
13	11.57	21	11.4	.0	27.5	1.4	59.7
13	12.04	21	13.5	.0	23.8	1.6	61.1
13	12.05	21	13.0	.0	24.8	1.2	61.0
15	11.25	21	14.0	.0	23.8	.6	61.6
15	11.26	21	14.1	.0	23.4	1.9	60.6
15	12.02	21	15.1	.0	24.8	2.3	57.8
		Average	13.8	.0	24.0	1.6	60.6
Nov. 9	10.48	24	13.0	.0	25.8	2.1	59.1
9	10.58	26	14.3	.0	25.4	1.5	58.9
9	10.48	27	15.4	.0	26.0	2.1	56.5
9	10.49	27	13.9	.0	24.0	2.1	59.9
13	11.46	27	13.0	.0	24.0	1.3	61.7
13	12.04	27	14.2	.0	23.6	1.7	60.5
15	11.27	27	14.2	.0	24.6	2.0	59.5
15	12.06	27	15.2	.0	23.2	2.6	59.0
		Average	14.2	.0	24.6	1.9	59.4

TABLE 13.—*Analyses of gas samples on plane 2, 10 feet below stock line, and 53 feet 4 inches above tuyère level*—Continued

Date	Time	Distance from inwall, inches	Per cent by volume				
			CO_2	O_2	CO	H_2	N_2
Nov. 9	10.56	32	12.2	0.0	26.8	2.1	58.7
9	10.40	33	14.4	.0	26.0	2.1	60.9
9	10.49	33	15.0	.0	22.8	1.3	57.4
13	11.41	33	13.2	.0	22.8	1.3	62.6
13	12.01	33	14.1	.0	22.8	2.1	61.0
13	12.02	33	14.4	.0	22.7	1.3	61.6
15	11.26	33	13.9	.0	23.4	2.1	60.6
15	11.27	33	13.7	.0	23.4	1.9	61.0
15	12.06	33	14.1	.0	25.2	2.7	58.0
		Average	13.9	.0	24.0	1.9	60.2
Nov. 9	10.51	39	14.1	.0	24.9	2.0	59.0
9	10.52	39	11.5	.0	27.2	1.6	59.7
9	10.54	39	12.8	.0	27.2	2.6	57.4
13	11.42	39	13.1	.1	24.2	.7	62.0
13	11.43	39	13.1	.0	22.9	.3	63.7
13	12.01	39	14.7	.0	23.9	1.6	59.8
13	12.02	39	14.4	.0	24.6	1.4	59.6
15	11.28	39	13.1	.0	24.6	2.3	60.0
15	12.00	39	11.6	.0	26.4	1.5	60.5
		Average	13.1	.0	25.1	1.6	60.2
Nov. 13	11.43	45	14.0	.0	25.0	1.2	59.8
13	12.01	45	14.6	.0	24.2	.5	60.7
13	12.04	45	14.0	.0	24.4	1.1	60.5
15	11.29	45	11.2	.0	27.0	2.1	59.7
15	11.50	45	11.0	.0	27.5	1.9	59.6
15	11.59	45	9.0	.0	28.8	1.3	60.7
		Average	12.3	.0	26.2	1.4	60.1
Nov. 13	11.44	51	13.0	.0	23.8	1.7	61.5
13	11.45	51	13.1	.0	25.1	1.5	60.3
13	11.58	51	13.3	.0	24.5	1.4	59.7
13	11.59	51	13.3	.0	24.7	1.2	60.8
15	11.31	51	9.9	.0	28.6	2.0	60.5
15	11.32	51	9.2	.0	28.2	1.3	61.3
15	11.53	51	7.9	.0	29.6	1.7	59.8
		Average	11.4	.0	26.5	1.5	60.6
Nov. 13	11.15	57	11.7	.0	25.8	1.6	60.9
15	11.32	57	6.9	.0	34.0	1.9	57.2
15	11.53	57	5.9	.0	31.0	1.5	61.6
		Average	8.1	.0	30.2	1.6	60.1
Nov. 13	11.46	63	10.9	.0	28.8	.3	60.0
13	11.56	63	11.4	.0	26.3	1.6	60.7
13	11.55	63	11.2	.0	25.5	1.1	62.2
15	11.33	63	4.2	.0	33.6	1.7	60.5
15	11.34	63	5.6	.0	31.8	1.6	61.0
15	11.35	63	4.8	.0	32.1	1.6	61.5
		Average	8.0	.0	29.7	1.3	61.0
Nov. 13	11.47	69	10.6	.0	28.2	1.3	59.9
13	11.54	69	8.2	.0	29.5	1.3	61.0
13	11.55	69	9.6	.0	28.3	1.4	60.7
13	11.56	69	12.4	.0	26.8	1.2	59.6
15	11.35	69	4.8	.0	32.2	1.6	61.4
15	11.36	69	3.5	.0	32.2	2.0	62.3
15	11.37	69	4.9	.0	32.8	1.6	60.7
15	11.55	69	3.1	.0	35.4	1.3	60.2
		Average	7.1	.0	30.7	1.5	60.7
Nov. 13	11.43	75	7.7	.0	31.4	1.2	59.7
13	11.48	75	7.2	.0	31.2	1.6	60.0
13	11.49	75	7.4	.0	31.6	1.3	59.7
15	11.36	75	4.1	.0	31.0	1.7	63.2
15	11.53	75	3.1	.0	34.2	1.6	61.1
		Average	5.9	.0	31.9	1.5	60.7

Table 13.—*Analyses of gas samples on plane 2, 10 feet below stock line, and 53 feet 4 inches above tuyère level*—Continued

Date	Time	Distance from inwall, inches	Per cent by volume				
			CO_2	O_2	CO	H_2	N_2
Nov. 13	11.49	81	4.0	0.0	32.3	1.8	61.9
13	11.49½	81	8.0	.0	28.9	1.6	61.5
13	11.50	81	8.1	.0	30.3	1.8	59.8
15	11.38	81	4.2	.0	34.6	1.7	59.5
15	11.51	81	2.4	.0	34.4	1.6	60.6
	11.51½	81	2.7	.0	34.8	1.9	60.6
		Average	4.9	.0	32.6	1.7	60.8
Nov. 13	11.50	87	6.2	.0	32.6	1.8	59.4
13	11.52	87	6.4	.0	31.4	1.4	60.8
13	11.53	87	7.5	.0	31.0	1.8	59.7
15	11.38	87	6.3	.0	32.2	1.7	59.8
15	11.40	87	6.0	.0	32.0	2.0	60.0
15	11.52	87	5.4	.0	32.2	1.6	59.8
15	11.52½	87	4.2	.0	32.2	1.9	61.7
		Average	5.9	.0	32.1	1.7	60.3
Nov. 13		93	4.6	.0	32.4	1.6	61.4
15	11.40	93	6.9	.0	29.9	1.0	62.2
15	11.41	93	6.6	.0	31.8	.8	60.8
15	11.49	93	6.6	.0	31.8	1.7	59.9
15	11.50	93	4.2	.0	32.2	1.4	62.2
15		93	4.1	.0	32.6	1.9	61.4
		Average	5.5	.0	31.7	1.4	61.4
Nov. 13		99	3.1	.0	35.0	1.3	60.7
15	11.15	99	6.1	.0	31.6	2.1	60.2
15	11.41	99	4.1	.0	34.2	1.4	58.4
		Average	4.3	.0	33.6	1.6	60.5
Nov. 13		105	2.1	.0	35.2	1.9	60.8
15		105	5.5	.0	33.6	1.7	59.2
15		105	6.2	.0	32.2	1.6	60.0
		Average	4.6	.0	33.6	1.7	60.1
		ANALYSES OF TOP GAS					
Nov. 9	9.30		9.5	0.0	29.0	1.5	60.0
9	1.00		9.4	.0	28.6	1.5	60.5
9	2.00		9.3	.0	28.1	1.6	61.0
13	9.45		10.1	.0	26.0	2.0	61.9
13	10.00		10.0	.0	26.8	2.0	61.2
13	1.30		11.2	.0	29.1	1.3	58.4
15	11.00		10.4	.0	28.4	2.0	59.2
15	1.00		11.3	.0	28.8	2.4	57.5
		Average	10.1	.0	28.1	1.8	60.0

Table 14.—*Analyses of gas samples on plane 1, 3 feet below stock line and 63 feet 4 inches above tuyère level*

Date	Time	Distance from inwall, inches	Per cent by volume				
			CO_2	O_2	CO	H_2	N_2
Oct. 13	1.15	0	10.7	0.0	27.6	3.2	58.5
Nov. 20	9.50	0	12.6	.0	24.0	1.6	61.8
20	10.00	0	10.9	.0	28.4	.9	62.8
20	1.50	0	8.8	.0	27.4	1.6	62.2
20	3.55	0	12.0	.0	23.1	.8	64.1
20	4.48	0	12.4	.0	22.8	1.5	63.3
30	9.00	0	10.2	.0	26.4	2.1	61.3
30	9.01	0	9.5	.0	27.2	1.3	62.0
30	9.03	0	10.1	.0	29.8	1.6	58.5
30	9.36	0	9.6	.0	28.6	1.8	60.0
30	9.38	0	10.1	.0	29.6	1.8	58.5
		Average	10.6	.0	26.5	1.7	61.2

TABLE 14.—*Analyses of gas samples on plane 1, 3 feet below stock line and 63 feet 4 inches above tuyère level*—Continued

Date	Time	Distance from inwall, inches	Per cent by volume				
			CO_2	O_2	CO	H_2	N_2
Dec. 1	10.40	2	11.6	.0	27.2	1.6	59.6
1	10.41	2	12.0	.0	26.8	1.4	59.8
1	11.25	2	11.8	.0	27.0	1.7	59.5
		Average	11.8	.0	27.0	1.6	59.6
Nov. 20	1.23	4	10.2	.0	26.1	2.3	61.4
20	1.32	4	10.5	.0	26.1	2.1	61.3
20	1.34	4	9.5	.0	25.6	1.3	63.6
20	1.35	4	10.2	.0	28.0	1.7	60.1
30	9.05	4	11.3	.0	26.2	2.3	60.2
30	9.37	4	11.0	.0	26.5	2.0	60.5
Dec. 1	10.40	4	11.2	.0	25.4	2.7	60.7
		Average	10.5	.0	26.3	2.1	61.1
Nov. 30	9.06	12	11.5	.0	25.0	2.4	61.1
30	9.08	12	12.8	.0	24.0	3.3	59.9
30	9.39	12	11.6	.0	26.4	1.5	60.5
Dec. 1	10.33	12	10.9	.0	26.2	1.5	61.4
1	10.34	12	11.9	.0	23.6	2.2	62.3
1	10.35	12	12.0	.0	26.0	1.4	60.6
1	10.36	12	11.1	.0	24.4	2.2	62.3
1	10.38	12	13.4	.0	22.2	2.5	61.7
		Average	11.9	.0	24.7	2.1	61.3
Nov. 20	1.37	18	10.3	.0	25.6	1.9	62.2
20	1.37	18	10.1	.0	27.8	2.1	60.0
30	9.07	18	12.8	.0	25.4	1.8	60.0
30	9.40	18	12.6	.0	25.6	1.9	59.9
Dec. 1	10.33	18	12.2	.0	25.9	1.6	60.3
1	10.33	18	11.0	.0	29.3	1.4	58.3
		Average	11.5	.0	26.6	1.8	60.1
Nov. 20	1.38	24	9.2	.0	25.0	1.3	64.5
20	1.40	24	10.3	.0	27.4	1.8	60.5
20	1.43	24	10.3	.0	26.7	1.6	61.4
30	9.08	24	12.2	.0	26.0	1.8	60.0
30	9.10	24	12.8	.0	23.4	2.1	61.7
30	9.42	24	11.3	.0	26.9	2.6	59.2
Dec. 1	9.31	24	12.3	.0	25.8	2.4	59.5
1	9.31	24	12.0	.0	25.6	1.9	60.5
		Average	11.3	.0	25.8	1.9	61.0
Nov. 20	1.44	30	10.3	.0	26.6	1.6	61.5
20	1.45	30	10.8	.0	26.2	2.1	60.9
20	1.48	30	9.7	.0	27.6	1.5	61.2
20	1.52	30	14.2	.0	24.4	1.5	59.9
20	1.59	30	12.7	.0	24.4	2.4	60.5
Dec. 1	10.30	30	10.5	.0	29.0	1.9	58.6
1	10.32	30	11.0	.0	28.0	2.0	58.6
		Average	11.3	.0	26.8	1.9	60.0
Nov. 20	1.46	36	9.5	.0	27.2	1.0	62.3
20	2.01	36	11.9	.0	23.8	2.5	61.8
20	2.03	36	12.1	.0	24.5	2.0	61.4
20	2.04	36	12.3	.0	24.6	2.0	59.4
20	2.05	36	12.5	.0	25.0	1.8	60.7
20	2.06	36	12.6	.0	25.8	1.5	60.1
20	2.06	36	11.9	.0	24.2	1.9	63.0
20	2.12	36	11.5	.0	25.2	2.2	61.1
20	2.42	36	13.5	.0	24.6	3.1	58.8
20	2.43	36	13.5	.0	23.8	3.0	59.7
20	2.45	36	12.8	.0	24.0	3.3	59.9
20	2.46	36	13.4	.0	22.4	2.5	61.7
20	2.47	36	14.0	.0	23.7	2.9	59.4
20	2.51	36	7.8	.0	24.2	2.8	65.2
20	2.54	36	12.0	.0	24.6	3.7	59.7
20	2.55	36	11.2	.0	24.2	2.7	61.9
20	2.58	36	13.4	.0	22.7	2.9	61.0
30	9.11	36	12.8	.0	24.0	3.2	60.0
30	9.12	36	13.0	.0	24.2	3.1	59.7
30	9.41	36	11.9	.0	24.2	1.9	63.0
Dec. 1	10.30	36	10.5	.0	29.0	1.9	58.6
1	10.32	36	11.0	.0	28.4	2.0	58.6
		Average	12.0	.0	24.7	2.5	60.8

TABLE 14.—*Analyses of gas samples on plane 1, 3 feet below stock line and 63 feet 4 inches above tuyère level*—Continued

Date	Time	Distance from inwall, inches	Per cent by volume				
			CO_2	O_2	CO	H_2	N_2
Nov. 20	2.38	42	9.2	.0	27.2	.5	63.0
20	2.38	42	10.9	.0	25.4	1.5	62.2
20	2.58	42	12.5	.0	23.9	3.2	60.4
20	2.59	42	12.3	.0	26.0	1.1	60.6
20	3.00	42	13.4	.0	23.5	1.6	61.5
30	9.13	42	11.2	.0	26.5	2.2	60.1
30	9.42	42	10.7	.0	27.2	1.0	61.1
Dec. 1	9.59	42	8.5	.0	29.6	1.9	60.0
1	10.30	42	7.2	.0	30.0	1.9	60.9
1	10.30	42	8.0	.0	30.5	2.0	61.5
		Average	10.4	.0	27.0	1.7	60.9
Nov. 30	9.15	48	9.5	.0	27.0	1.4	62.0
30	9.17	48	10.1	.0	27.8	2.1	60.0
30	9.42	48	9.2	.0	28.8	1.3	60.7
		Average	9.2	.0	27.8	1.6	61.4
Nov. 20	2.13	51	10.7	.0	27.2	1.0	61.1
20	3.00	51	9.4	.0	27.2	1.8	61.6
20	3.02	51	9.2	.0	27.4	2.0	61.4
20	3.04	51	9.7	.0	27.6	1.5	61.2
20	4.00	51	10.6	.0	27.0	1.4	61.0
20	4.00	51	10.3	.0	27.8	1.6	60.3
		Average	9.9	.0	27.3	1.5	61.3
Nov. 30	9.18	54	7.4	.0	29.9	1.6	61.1
30	9.19	54	7.7	.0	31.4	1.2	59.7
30	9.44	54	7.8	.0	29.4	2.8	60.0
Dec. 1	9.58	54	6.1	.0	32.0	1.6	60.3
1	10.28	54	6.2	.0	30.0	1.7	62.0
1	10.30	54	6.4	.0	31.3	.3	62.0
		Average	6.9	.0	30.7	1.5	60.9
Nov. 20	1.17	60	11.9	.0	25.8	2.1	60.2
20	2.28	60	11.7	.0	25.4	2.4	60.5
20	3.05	60	9.3	.0	26.6	1.9	62.2
20	3.06	60	8.1	.0	30.3	1.8	59.8
20	3.08	60	8.7	.0	28.6	2.0	60.7
20	3.55	60	9.9	.0	28.4	1.2	60.5
20	3.56	60	8.0	.0	29.4	2.0	60.6
20	3.57	60	8.5	.0	29.6	2.1	59.8
30	9.20	60	5.6	.0	32.0	1.5	60.9
30	9.21	60	6.2	.0	32.2	1.5	60.1
30	9.46	60	5.6	.0	31.8	1.6	61.0
30	9.47	60	6.7	.0	31.0	1.0	61.3
Dec. 1	10.24	60	3.0	.0	33.4	1.0	62.6
1	10.26	60	4.5	.0	32.0	1.0	62.5
1	10.27	60	4.0	.0	34.0	1.7	60.3
		Average	7.5	.0	30.0	1.7	60.8
Nov. 20	3.09	66	6.9	.0	30.3	2.2	60.6
20	3.10	66	6.2	.0	32.2	1.6	60.0
20	3.11	66	6.0	.0	33.0	1.9	59.1
20	3.53	66	5.9	.0	31.0	1.5	61.6
20	3.54	66	5.9	.0	31.0	1.5	61.6
30	9.22	66	4.2	.0	34.6	1.7	59.5
30	9.23	66	4.4	.0	33.2	1.5	60.9
30	9.48	66	4.4	.0	32.8	1.7	61.1
30	9.49	66	4.4	.0	34.6	1.6	59.2
Dec. 1	10.17	66	3.1	.0	35.3	.4	61.2
1	10.22	66	4.1	.0	33.1	.7	62.1
1	10.22	66	2.4	.0	34.7	2.2	60.7
		Average	4.8	.0	33.0	1.5	60.7
Nov. 20	3.13	72	3.0	.0	35.0	1.3	60.7
20	3.14	72	2.3	.0	36.6	1.7	59.4
20	3.50	72	3.1	.0	35.2	1.9	59.8
20	3.52	72	1.2	.0	34.6	1.2	63.0
30	9.24	72	4.7	.0	34.2	1.6	59.5
30	9.25	72	3.8	.0	34.6	1.8	59.8
30	9.50	72	3.4	.0	36.0	1.4	59.2

TABLE 14.—*Analyses of gas samples on plane 1, 3 feet below stock line and 63 feet 4 inches above tuyère level*—Continued

Date	Time	Distance from inwall, inches	Per cent by volume				
			CO_2	O_2	CO	H_2	N_2
Dec. 1	10.10	72	1.3	0.0	35.4	0.8	62.5
1	10.12	72	1.2	.0	34.6	1.2	63.0
1	10.14	72	1.8	.0	38.9	.6	58.7
1	10.14	72	1.9	.0	32.4	2.9	62.8
		Average	2.5	.0	35.2	1.5	60.8
Nov. 20	3.16	78	2.0	.0	36.0	1.2	59.8
20	3.19	78	1.2	.0	34.6	1.2	63.0
20	3.48	78	2.3	.0	34.4	2.0	61.3
20	3.49	78	2.0	.0	35.6	1.8	60.6
30	9.26	78	1.9	.0	34.6	2.8	60.7
30	9.27	78	2.0	.0	34.4	2.8	60.8
30	9.51	78	1.1	.0	35.4	1.4	62.1
30	9.52	78	2.2	.0	36.2	1.6	60.0
Dec. 1	10.09	78	3.1	.0	34.8	1.2	60.9
1	10.07	78	3.0	.0	35.0	1.1	60.9
1	10.17	78	2.3	.0	35.2	.6	61.9
		Average	2.1	.0	35.1	1.6	61.2
Nov. 30	9.28	84	2.0	.0	34.6	2.4	61.0
30	9.53	84	2.2	.0	34.0	2.8	61.0
30	9.54	84	2.5	.0	36.2	1.0	60.3
Dec. 1	10.06	84	2.3	.0	36.6	1.7	59.4
Nov. 30	3.22	86	2.0	.0	37.2	1.6	59.2
30	3.23	86	1.2	.0	33.2	1.2	64.4
30	3.25	86	1.1	.0	33.6	1.3	64.0
30	3.44	86	1.2	.0	34.6	1.2	63.0
30	3.46	86	2.8	.0	35.2	1.7	60.3
Dec. 1	10.03	86	2.6	.0	37.2	.5	59.7
1	10.04	86	2.3	.0	37.0	1.8	58.9
		Average	2.0	.0	35.4	1.6	61.0
Nov. 30	9.29	90	2.9	.0	35.2	1.8	60.1
30	9.55	90	3.2	.0	34.0	2.0	60.8
30	9.56	90	3.5	.0	34.0	1.2	61.3
30	9.57	90	3.0	.0	35.6	1.4	60.0
Dec. 1	10.02	90	2.4	.0	36.2	2.4	59.3
1	10.15	90	2.3	.0	35.2	1.1	61.4
Nov. 20	3.28	92	2.4	.0	36.4	1.3	59.9
20	3.30	92	2.5	.0	36.6	1.8	59.1
20	3.40	92	2.5	.0	36.6	1.4	59.5
20	3.42	92	3.0	.0	36.0	1.2	59.8
		Average	2.8	.0	35.6	1.5	60.1
Dec. 1	9.58	96	2.4	.0	35.0	2.3	60.3
1	10.00	96	2.8	.0	36.0	.7	60.0
1	10.01	96	2.4	.0	36.4	1.3	59.9
		Average	2.5	.0	35.9	1.4	60.2
		ANALYSES OF TOP GAS					
Oct. 13	9.35		13.3	0.0	24.9	4.2	57.6
Nov. 20	9.15		10.0	.0	28.2	2.5	59.3
30	2.15		10.5	.0	28.6	1.2	60.0
Dec. 1	9.00		9.0	.0	29.8	3.3	57.9
1	10.00		8.4	.0	30.0	2.6	59.0
1	10.45		7.2	.0	30.0	2.5	60.3
		Average	9.8	.0	28.6	2.7	58.9

The average of 44 samples of top gas taken during the period of gas sampling on planes 1 to 6 is: CO_2, 9.9 per cent; O_2, none; CO, 28.1 per cent; H_2, 2 per cent; and N_2, 60 per cent.

MISCELLANEOUS GAS SAMPLING

Table 15 gives analyses of a number of samples that were taken through hole 1 when the center of the stock line was below the level of the hole. Figure 20 shows the position of the sample tube in respect to the stock line. The end of the sample tube is at the center of the furnace, just over the stock.

TABLE 15.—*Analyses of gas samples taken at center of the furnace on top of the stock*

Date	Per cent by volume				
	CO_2	O_2	CO	H_2	N_2
Nov. 20	2.1	0.0	36.0	1.3	60.6
	2.4	.0	33.8	1.2	62.6
	1.6	.0	35.1	1.4	61.9
	1.9	.0	34.2	1.6	62.3
	1.0	.0	35.6	2.0	61.4
Nov. 30	1.8	.0	34.2	1.8	62.2
	1.8	.0	34.6	1.6	62.0
	2.2	.0	34.0	1.4	62.4
	2.0	.0	34.8	1.6	61.6
	1.8	.0	34.2	1.8	62.2
	1.6	.0	34.0	2.0	62.4
	1.8	.0	35.8	2.1	60.3
Average	1.8	.0	34.4	1.7	62.1

After cast, when the furnace was dry, a gas-sampling tube was inserted in the cinder notch. Samples taken on the edge of the wall and at a point 3 feet from the inwall gave the results in Table 16.

TABLE 16.—*Analyses of gas samples taken through cinder notch*

Distance from inwall, inches	Per cent by volume				
	CO_2	O_2	CO	H_2	N_2
0	0.0	0.0	35.4	0.8	65.8
0	.2	.0	35.9	.3	63.6
36	.0	.0	35.2	1.2	63.4
36	.2	.0	35.6	.2	64.0
Average	.1	.0	35.5	.6	63.8

DISCUSSION OF RESULTS OF GAS SAMPLING

During 1922 a series of gas samples was taken at the tuyère plane of 14 blast furnaces; Perrott and Kinney [13] reported the results at 11 of these. The results showed that the combustion of coke in the blast-furnace hearth is complete some 32 to 40 inches from the nose of the tuyère. This distance is measured on a horizontal line between the center of the nose of the tuyère and the center of the furnace at the level of the tuyères. In the discussion of this paper the question

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[13] Perrott, G. St. J., and Kinney, S. P., "Combustion of coke in the blast-furnace hearth"; Trans. Am. Inst. Min. and Met. Eng., vol. 69, 1923, pp. 543–584.

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was raised as to the height at which oxygen is to be found vertically above the tuyères. It was suggested[14] that the combustion zone turned upward near the tuyère and extended to a point high up in the bosh of the furnace. To obtain an answer to this question and to make comparison with the gas samples taken at the experimental blast furnace at Minneapolis, the sampling of the tuyère gas was supplemented by the collection of samples from a number of planes between the tuyère plane and the stock line.

RESULTS OF SAMPLING AT THE TUYÈRE PLANE

Table 9 and Figures 7 and 8 give details regarding analyses of gas samples from the tuyère plane. Distances are indicated in inches from a point at the center of the nose of the tuyère along the center line of the tuyère. The samples were taken through tuyères 5 and 11. The curves, Figure 7, show the results, and Figure 8 offers a comparison of the results of tuyère gas sampling at 13 other furnaces.

COMBUSTION OF COKE AT THE TUYÈRE LEVEL

Sampling of tuyère gas at this southern furnace and at other furnaces has given a definite idea of the penetration of the combustion zone toward the center of the furnace. Figure 18 is a horizontal section of the furnace at the tuyère level. The combustion zones, shown as ellipses, are labeled. In the central zone,[14a] 82 inches in diameter, no combustion is taking place. As no samples were obtained between the tuyères in the hearth plane, the exact shape of the combustion zone is unknown. In 1893, Van Vloten[15] found that the gas in the tuyère plane between the tuyères had the composition of bosh gas; this finding showed that the combustion zones in the furnace investigated did not overlap. Van Vloten's results have been discussed by Perrott and Kinney.[16]

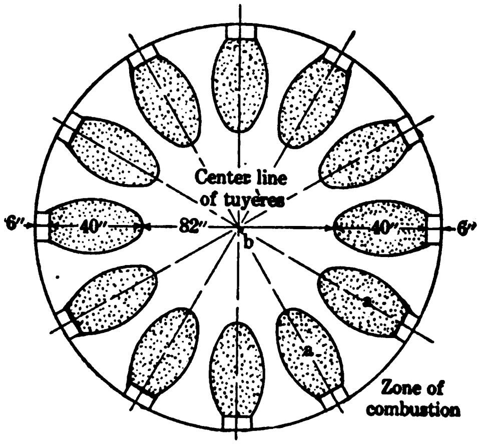

FIGURE 18.—Plan of tuyère plane, showing penetration of combustion zones, a

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[14] Rose, H. J., "Coke structure and combustibility," presented before meeting of Eastern States Blast Furnace and Coke Oven Assoc., Pittsburgh, Pa., Oct. 5, 1923. (Not published.)

Johnson, J. E., Jr., Principles, Operation, and Products of the Blast Furnace. Part 1, 1918, 551 pp.

[14a] Designated zone b in the discussion that follows.

[15] Van Vloten, W., "Die Verbrennung in Gestell des Hochofens": Stahl u. Eisen, Jahrg. 13, 1893, pp. 26–30.

[16] Perrott, G. St. J., and Kinney, S. P., work cited.

From a study of the gas analyses in the tuyère plane (6) and in plane 5 (27 inches above the tuyères), Figure 19 has been constructed; in it a vertical section of the combustion zones is marked *a* and *a′*.

CONCENTRATION OF CARBON MONOXIDE AT THE CENTER OF THE TUYÈRE PLANE

FUNCTION OF ZONE *b*

Figures 7, 8, and 9 show the high concentration of CO in the center of the furnace. This may be due to (1) the formation of cyanides of other reactions producing CO, the so-called direct reduction, and (2) the low velocity of the gas stream in zone *b*. The velocity of the gas is highest at the nose of the tuyère and in zone *a*, and at a minimum in the center of the tuyère level. If the velocity is at a minimum in zone *b*, reactions which produce CO from C of the coke and from O_2 of the charge will have a disproportionately important effect on the composition of the gas. For example, the formation of a relatively small amount of cyanide will dilute the nitrogen and increase the CO content of the gases passing through zone *b*. If gas flow and composition were uniform across the tuyère plane, the CO content of the gas at any point in the plane should not exceed 34.34 per cent. It is interesting to note that this was true with the Bureau of Mines experimental furnace at Minneapolis,[17] where the hearth area was covered by the combustion zone and no zone similar to *b* was found.

The high content of CO in zone *b* was due to conditions that existed only in the tuyère region, as is evident from the analyses of gas samples taken on plane 5. Plane 4 (see Table 11 and fig. 10) is 19.25 feet above the tuyère level. The average CO content of the gas in zone *b* decreases as plane 4 is approached. On plane 4 the gas is practically bosh gas; this fact suggests that the gas high in CO from the center of the furnace is mixed before it reaches plane 4 and that the presence of high CO in zone *b* below is due to the formation of CO by relatively minor reactions in an area of such low gas velocity that they cause no noticeable change in the composition of the gas in plane 4.

Whether or not zone *b* has any valuable function is doubtful; the furnace might work more efficiently if this zone were absent. The authors have shown by relative temperature measurements with water-cooled sampling tubes and by actual thermoelectric measurements that the temperature in zone *b* is lower than in zone *a*. Table 21 gives the temperature measurements. The formation of cyanides and so-called direct reduction take place in this zone. The flow of stock and of gas is at a minimum at zone *b*.

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[17] Royster, P. H., Joseph, T. L., and Kinney, S. P., "Reduction of iron in the blast furnace": Blast Furnace and Steel Plant, vol. 12, 1924, pp. 35–38 .

GAS SAMPLING AT PLANE 5

Table 10 and Figure 9 show that only a trace of oxygen (0.4 per cent or less) was found at any point in the line of sampling on plane 5; this indicates that the oxygen has been consumed in the process of combustion by the time it reaches a plane 27 inches above the center line of the tuyères.

The penetration of the combustion zone in a vertical direction is practically the same as that in a horizontal direction at the tuyère level. On the tuyère plane the oxygen disappears at a distance of 30 inches measured on a horizontal line drawn from the center of the nose of the tuyère to the center of the furnace at the tuyère level.

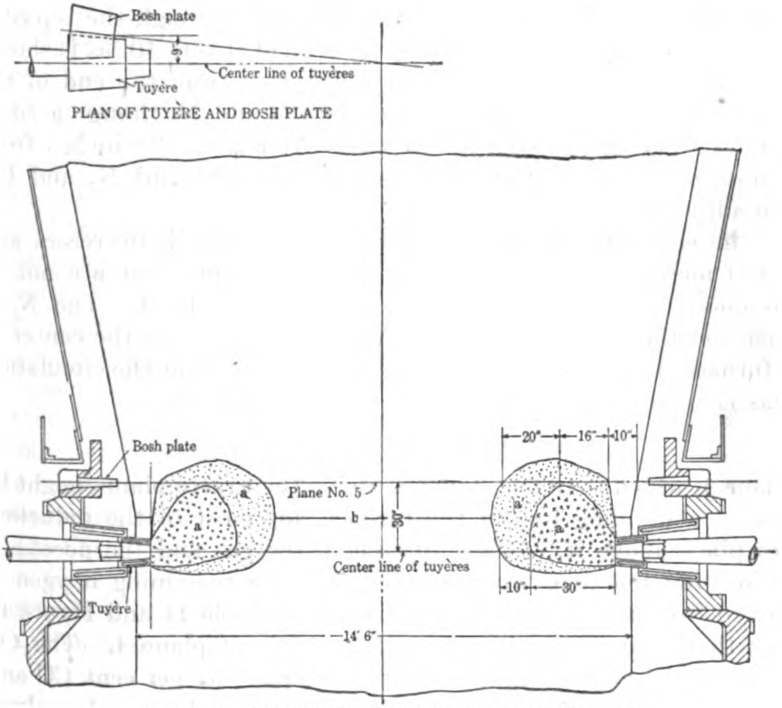

FIGURE 19.—Approximate size and shape of combustion zones

Figure 19 shows the approximate size and shape of the combustion zone. The volume represented by *a* is that part of the combustion zone where free O_2 is found, and volume a^1 is that part where CO_2 is present. The free O_2 has been consumed before it can enter the latter zone.

Outside of this zone (in *b*) both O_2 and CO_2 have disappeared; the gases in the bosh, especially near the combustion zone, are composed of CO, H_2, and N_2. If no secondary reactions, such as oxidation of CO_2, so-called direct reduction, or the formation of cyanides, were taking place in the bosh of the furnace, the gases in the bosh would have the composition of bosh gas—34.34 per cent CO, a little H_2, and the remainder N_2. However, such is not the fact; these secondary reactions and poor circulation of gases through the bosh play havoc with the gas composition. The variation in composition of the gases at the level of sample hole 5 is shown in the curves of Figure 9. At the inwall the gas has the approximate composition of bosh gas; 14 samples are shown in Table 10. The analyses in Table 16, taken at the cinder notch, showed a similar composition.

On examining Figure 19 and the curves of Figure 9 the reader will see that the line of gas sampling on plane 5 cuts through the top edge of the combustion zone in front of the nose of tuyère 10, as is shown by the presence of 7.8 per cent CO_2 20 inches from the end of the water-cooled plate. The percentages of CO and N_2 change according to the percentage of CO_2 present. At a point 30 inches from the nose of the plate CO_2 has again disappeared and N_2 and CO again adjust themselves.

As the center of the furnace is approached the N_2 decreases and the CO increases. These changes are fairly rapid, but are not as pronounced as those taking place at the tuyère level. The N_2 is higher and the CO lower at the elevation of plane 5 in the center of the furnace than at the tuyère level; this indicates that the circulation of gas is slightly better at plane 5 than on plane 6.

GAS SAMPLING AT PLANE 4

Plane 4, which is 19 feet 3 inches above the tuyère plane, might be taken as a dividing line in the furnace, for most of the reduction takes place above it. Below this plane the gas and the necessary heat for the reactions are produced and the remaining oxygen is removed from the charge. Examination of Table 11 and Figure 10 shows that a uniform gas composition exists at plane 4. The CO content of the gases is about that of bosh gas—34 per cent CO and 66.0 per cent N_2. No free O_2 is found on the plane and analysis shows but little CO_2. Because the reduction takes place in the lower part of the furnace, the gases at plane 4 contain a slight excess of O_2 in combination with C. The excess O_2 in the gases at this plane is of course present as CO, due to the temperature.

FLOW OF GASES AT PLANE 4

The gases on plane 4 have a constant composition; however, it can not be said from this that the flow is uniform throughout the plane. The gas flow is probably at a maximum in the center of the plane and at a minimum on the edge. This condition is due to the effect of the center zone *b*, the downward flow of solid materials toward the tuyères, and the porosity of the charge in the center of the stack.

GAS SAMPLING AT PLANE 3

Experience has shown that gas samples taken at the inwall may or may not have the same composition from day to day; it has also shown that such samples do not represent conditions existing a short distance from the inwall and by no means those at the center of the furnace. To obtain comparable and representative results it was necessary to take numerous duplicate samples on any radius tested. These samples have been duplicated on one and several days, at times when the furnace was believed to be working normally.

Analyses of gas samples on plane 3 have been given in detail in Table 12 and plotted in Figures 11 and 14 to 17, inclusive, so that the reader may have some conception of the degree of variation in results from day to day. Table 12 and Figure 11 have been prepared to show the average of results obtained, while Figures 14 to 17 indicate the daily variation.

Figure 9 represents, in a measure, the reduction that has taken place between planes 3 and 4. If the reader examines the analyses of gas samples on plane 4 (fig. 10) he will note that the composition of the gas throughout the plane is constant; the approximate composition is that of bosh gas, except for a little CO_2. Some reduction has taken place below plane 4, as is indicated by the CO_2 content of the gases and the small excess of O_2 present.

Conditions are different in plane 3; part of the ascending gas stream has reacted with iron oxides to produce CO_2, but part has not reacted; consequently the latter has approximately the same composition as it had at the elevation of plane 4.

The CO_2 curve of Figure 11 shows that for 15 inches from the inwall the CO_2 has increased rapidly. From this point to 50 inches there is a slight falling off, and a more rapid decrease as the center of the furnace is approached.

DAILY VARIATION OF GASES

Figures 14 to 17 show the daily variation in the reduction at plane 3, and the reader will note that the curves are similar in form. The CO_2 increases with distance from the inwall, but at a point 40 to 50 inches from the inwall the CO_2 content declines rapidly. The distance of this point from the inwall varies from day to day and from hour to hour. This fact distinctly indicates variation in the working of the furnace; at one period the point of maximum CO_2 is near the wall; later it is nearer the center. In general, the curves have similar characteristics and probably represent a condition existing on any radius.

It is significant that the extent of penetration of the combustion zone on plane 6 (tuyère plane) is also 40 inches, that is, directly under the zone of active reduction on plane 3.

GAS SAMPLING AT PLANE 2

Table 13 and Figure 12 show that the curves have the same characteristic shape as those for plane 3, which is 11 feet 7 inches below plane 2. The CO_2 curve indicates that the gases containing most CO_2 are near the inwall. At a point 40 inches from the inwall the CO_2 content of the gases diminishes rapidly until the center of the furnace is reached. The CO_2 content of the gases in the central part of the plane is approximately one-third of those near the wall. Table 13 gives a number of examples of gases which contain notable quantities of CO_2, namely, 19.1, 19.3, and 18.3 per cent at the inwall. At 3 inches from the inwall, 17.9 per cent of CO_2 is shown, and so on. The CO : CO_2 ratio is 1 : 1. At the center of the furnace the average CO_2 is 4.3 per cent. Comparison of the results shown in Figure 12 for CO_2 for a distance of 40 inches from the inwall with those shown beyond that point shows that the CO_2 is decidedly lower at the center than near the wall.

The analyses of samples of top gas in Table 13 show that the average CO_2 in this gas is 10.1 per cent. If the reader examines the CO_2 curve in Figure 12, he will note that the part of the plane included between the 0 and 40-inch points contains gases carrying 14 per cent of CO_2, the average of 77 samples taken on three different days when the furnace was working normally. In other words, the CO_2 content of the gases in one part of the furnace is much greater than that of the top gas.

Why is it not possible to extend to the entire plane the good work being done in one part of the plane? It is suggested that uniform movement of stock might remedy the condition and the column of low CO_2 content in the center of the furnace might be removed.[18]

Comparison of the CO_2 curve for plane 3 in Figure 11 with the CO_2 curve for plane 2 in Figure 12 shows that there was a decided increase in CO_2 while the gases passed from plane 3 to plane 2, which indicates a progression in reduction between the two planes. The CO curve follows the CO_2 curve and the N_2 remains the same on both planes. Part of the CO_2 present is due to calcination of limestone. Table 20 shows the amount.

In plane 2, as in plane 3, the falling off in the CO_2 content of the gases occurs at a point 40 inches from the inwall, and this point is equal to the distance of penetration of the combustion zone at the tuyère level.

GAS SAMPLING AT PLANE 1

Figure 13 shows that the curves have the same characteristic form as those for planes 2 and 3. The curve indicates that the CO_2 is highest at points less than 40 inches from the inwall. After the

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[18] These factors were discussed at the blast-furnace conference of Engineers Society of Western Pennsylvania, Nov. 12, 1925. See Proceedings, vol. 41, Jan. 1926, pp. 447–459.

40-inch point has been reached the CO_2 content begins to fall, and the decline continues to the center of the furnace. Then the gas has approximately the composition of bosh gas, which would indicate that there is in the center of the furnace a column of gas which is not entering into the process of reduction. It is of interest to note that the gas at the center of plane 1 has the same composition as the gas on plane 4, that is, bosh gas.

COMPOSITION OF GAS ABOVE THE STOCK LINE

Further proof of the existence of bosh gas at the stock line of the furnace is given in Table 15 (see p. 32), which presents the analyses of a number of samples taken when the center of the stock line was let fall below the level of plane 1. The sample tube was driven through hole 1, through the stock near the wall of the furnace, to a point just above the stock at the center of the furnace. Figure 20 shows the position of the tube. Samples were thus collected in the gas stream above the stock before this gas had a chance to mix with the gases emerging from other parts of the stock. The results confirm the condition found in the stock in the center of the furnace on planes 1, 2, 3, and 4; that is, gases low in CO_2 are present at the center of the planes.

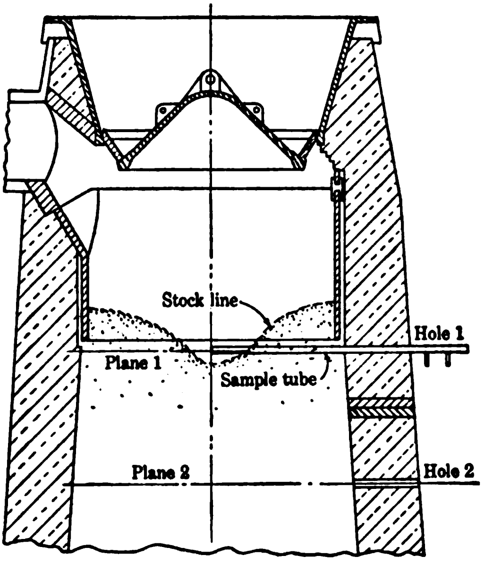

FIGURE 20.—Position of sampling tube for obtaining samples above the center of the stock column

In this connection it is of interest to note that, according to a letter from Dr. C. Bulle, June 17, 1925, the Verein deutscher Eisenhüttenleute, Warmestelle, Dusseldorf, Germany, was conducting at a

German blast furnace an investigation similar to the one reported here. Preliminary results from this investigation on sampling gases above the stock gives results similar to those reported in this paper.

ANALYSIS OF TOP GASES

The average analyses of samples of top gas taken as it entered the dust catcher, while the various planes were being sampled, indicate that this gas contained 9.9 per cent of CO_2. The result represents an integration over the area of the stock line. The top gas sampled represents a mixture of the gases low in CO_2 at the center of the furnace and those higher in CO_2 near the wall of the furnace. In other words, the gas containing 12 to 19 per cent CO_2, from points in the column of stock near the wall of the furnace, was diluted by the gas containing 2 per cent CO_2 to form the resultant top gas, which contained 9.9 per cent CO_2.

DISTRIBUTION OF FLOW OF GAS

If the CO_2 curve for plane 1 is integrated, the result should indicate the CO_2 content of the top gas. Integration shows 10.3 per cent CO_2, while actual sampling over the period of sampling of the planes shows 9.9 per cent, so the observed and calculated results are close. This result indicates that in the upper part of the furnace the gas flow per unit area of plane is fairly equal and that the gases high in CO_2 are being diluted by those lower in CO_2. On a few days it was noticed that an integration of the results of CO_2 on plane 1 gave a higher CO_2 content than the actual result of sampling the top gases. This fact might be taken to indicate that on these particular days the gas flow per unit area of the plane was not uniform, and that a large proportion of the gases was passing through the center column of stock, thus diluting the gases on the outer part of the plane.

REDUCTION IN VARIOUS PARTS OF THE FURNACE

That the composition of the gas on any plane varies with distance from the wall has been shown, therefore it has been necessary first to assume that the results of sampling on any radius will be representative of any other radius and then to integrate the curves for the average composition at any one plane. The average analyses of the gasses at planes 1, 2, and 3 have been determined thus.

Table 17 gives these average analyses and the volume, weight, and velocity of the gas at planes 1, 2, 3, and 4, compared with the composition of bosh gas and air. The gas analyses at the various planes are given as percentages by volume and weight. Temperatures and pressures of the various planes are recorded.

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TABLE 17.—*Analysis, volume, weight, and velocity of gas at planes 1, 2, 3, and 4, compared with bosh gas and air* [1]

Plane	Distance		Pressure, pounds per square inch	Temperature, °C	Gas analysis, per cent by volume				Gas analysis, per cent by weight				Weight per 100 cubic feet, pounds	Relative volume (air=1)[3]	Volume, cubic feet, at 65° F. and 30 inches of Hg.	Volume at temperature and pressure of plane, cubic feet	Velocity [4]		Velocity [5]		Weight of gas, pounds
	Above tuyères[2]	Below stock line			CO_2	CO	H_2	N_2	CO_2	CO	H_2	N_2					Feet per minute	Feet per second	Feet per minute	Feet per second	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
	Ft. in.	*Ft. in.*																			
Top gas				168.0	9.9	28.1	2.0	60.0	14.9	27.0	0.1	58.0	8.115	1.319	37,843	56,764	626	13.6	1,252	27.2	3,070.9
1	60 4	3 0	0.45	204.4	10.30	27.04	1.87	60.79	15.5	25.9	.1	58.5	8.142	1.301	37,326	59,348	772	12.8	1,544	25.6	3,055.4
2	53 4	10 0	2.3	465.5	12.14	26.50	1.69	59.67	18.1	25.1	.1	56.7	8.240	1.325	38,015	83,633	950	15.6	1,900	31.2	3,132.5
3	41 9	21 7	3.7	[6] 745.0	9.02	28.62	1.64	60.72	13.7	27.6	.1	58.6	8.117	1.302	37,355	[6] 104,220	986	16.4	1,972	32.8	3,032.1
4	19 3	44 1	10.4	[7] 853.0	1.10	33.6	.8	64.50	1.73	33.55	.06	64.65	7.810	1.228	35,232	[7] 79,976	532	8.8	1,064	17.6	2,751.6
Bosh gas				[8] 1,350.0	.0	34.10	.79	65.11	.0	34.16	.05	65.79	7.766	1.213	34,859	[8] 93,965	1,064	17.9	2,128	35.8	2,707.0
Air				513.8	.0	.0	[9] 20.91	79.09	.0	.0	[9] 23.15	76.85	8.072	1.000	28,691	[10] 36,150	[11] 15,340	[11] 257			2,315.9

[1] Composition of gas at each plane, derived from integration of average analysis of gas at various points between inwall and center of furnace.

[2] Distance above center line of tuyères.

[3] At 18° C. (65° F.) and 760 mm. Calculated from nitrogen content.

[4] Assuming furnace empty.

[5] Assuming that average charge contains approximately 50 per cent voids.

[6] Plane 3, gas volume calculated at 745° C., average temperature between inwall and center of furnace.

[7] Plane 4, gas volume calculated at 853° C., average temperature between inwall and center of furnace.

[8] Assuming average temperature across plane 3 feet above center line of tuyères to be 1,350° C. and gas to have composition of bosh gas.

[9] Oxygen.

[10] Volume at blast temperature and pressure.

[11] Velocity at nose of each tuyère; twelve 6-inch tuyères.

Figure 21 shows the relation between the velocity of the gases at the temperature and pressure of the plane and the distance above the tuyère level. Johnson[19] has said that furnaces are designed to obtain an approximately uniform velocity of gases throughout the stock column. The curve, however, shows that the velocity in this case is not constant along the vertical axes of the furnace.

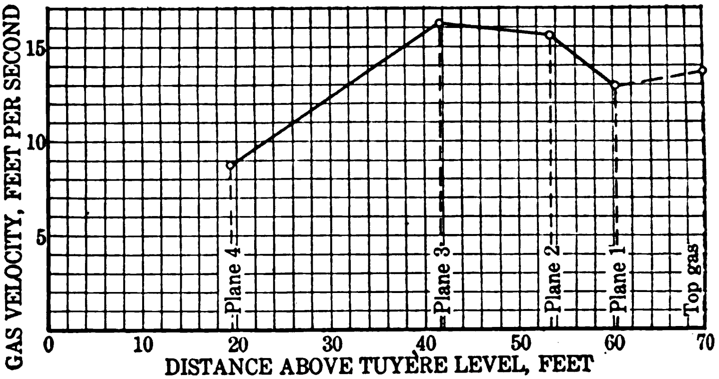

FIGURE 21.—Relation between velocity of gas, at temperature and pressure of plane, and distance from tuyère level

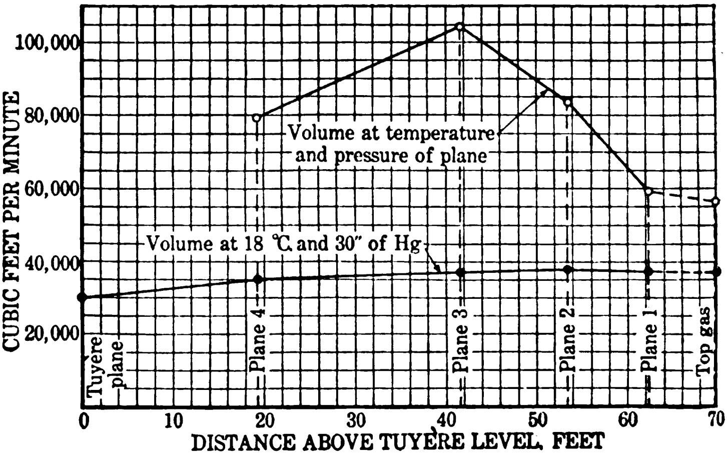

FIGURE 22.—Relation between volume of gas, at normal temperature and pressure and at temperature and pressure of the various planes, and the distance from the tuyère level

Figure 22 shows the volume of gas passing the various planes at the temperature and pressure of the planes and at the temperature and pressure of the entering air. The curve of the gas volume at the temperature and pressure of the various planes in the furnace

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[19] Johnson, J. E., Principles, Operation, and Products of the Blast Furnace. Pt. 1, 1918, 551 pp.

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shows that the volume increases rapidly until it reaches plane 3, and after passing this point the volume decreases.

Tables 18 and 19 give a number of comparisons between the composition of bosh gas and the average gas at various planes, calculations being made on the basis of volume and weight. In Table 18 the comparisons have been made by weight; the gases passing and the constituents of the gases passing each plane per minute have been calculated in pounds for the purpose of calculating various items and making comparisons with the results obtained in the balance sheet of materials (Tables 5 to 8). Figure 23 shows the gas components (N_2, O_2, C, and H_2) at the various planes. The first and last are constant, or practically so, throughout the passage of the gases through the furnace. The O_2 content shows marked increase up to plane 3, but the rate of increase is lower above this plane. The O_2 probably should show an increase with distance from the tuyère. The results are consistent with this for all planes except plane 2. According to integration, the gases at this plane contain more oxygen than is being removed from the furnace, an inconsistence which is doubtless due to the irregular flow of gases. The curves indicate the deposition of carbon, a fact confirmed by the recovery of samples of deposited carbon.

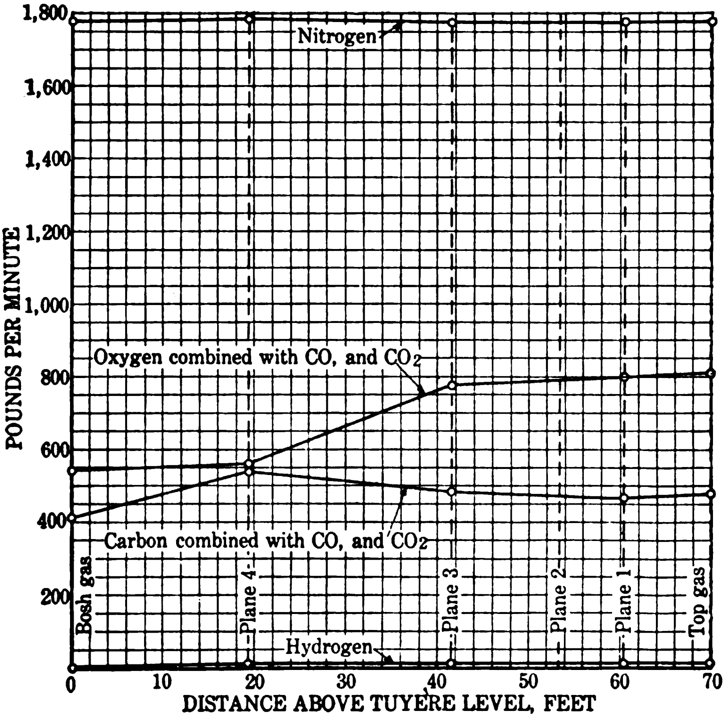

FIGURE 23.—Relation between gas constituents (percentage by weight) and distance above tuyères

TABLE 18.—*Comparison between bosh gas and composition of gases at various elevations, by weight*

Plane	Gas analysis, per cent by weight				Weight, pounds of gas passing plane per minute	Pounds of gas constituents passing plane per minute										Pounds of gas constituents passing plane per minute per 100 pounds nitrogen				
						Carbon dioxide (CO₂)		Carbon monoxide (CO)		Hydrogen (H₂)	Nitrogen (N₂)	Total carbon (C)	Total oxygen (O₂)	Excess—		Carbon dioxide (CO₂)		Carbon monoxide (CO)		H₂
	CO₂	CO	H₂	N₂		C	O₂	C	O₂					Carbon (C)	Oxygen (O₂)	C	O₂	C	O₂	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Top	14.9	27.0	0.1	58.0	3,070	124	334	355	474	3	1,780	479	808	66	259	70.6	187.5	195.5	276.0	1.6
1	15.5	25.9	.1	58.5	3,055	128	346	339	452	3	1,787	467	798	54	249	71.6	193.5	189.5	252.2	1.7
2	18.1	25.1	.1	56.7	3,133	154	413	337	449	3	1,777	491	862	78	313	86.6	232.1	190.0	253.0	1.7
3	13.7	27.6	.1	58.6	3,032	116	300	358	479	3	1,776	484	779	71	203	65.3	169.0	208.0	270.0	1.7
4	1.73	33.55	.06	64.65	2,752	13	34	396	528	2	1,779	541	562	128	13	7.3	19.1	222.8	297.0	1.1
Bosh gas	.0	34.16	.05	65.79	2,707	------	------	397	522	2	1,776	413	532	0	0	------	------	232.2	309.0	1.1
Air	.0	[1] 23.15	.0	76.85	2,316	------	[2] 536	------	------	------	1,779	------	536	------	------	------	[2] 301.0	------	------	------

[1] Oxygen.

[2] Free oxygen—air.

Figure 24 shows the O_2 and C combined as CO and CO_2 in the gases at various planes. The curve shows a decided decrease in CO content of the gases until plane 2 is reached; there the CO content shows slight increase. Oxygen and carbon combined with CO_2 increase up to plane 1, where a decrease is shown; as in Figure 23 these results show deposition of carbon.

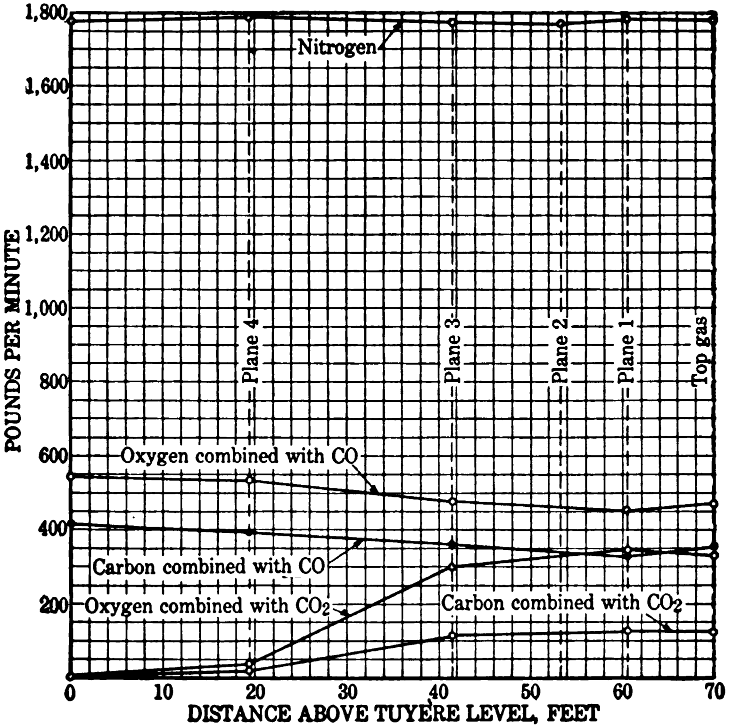

FIGURE 24.—Relation between O_2 and C combined with CO and CO_2 and distance above tuyère level

Figure 25 shows the relation between excess C and O_2 at the various planes.

In Table 19 a number of calculations have been made to enable the reader to compare the results of this investigation with those reported by others. The ratio of the percentage of CO_2 and CO to the sum of the $CO + CO_2$ in the gases is given, and these values have been plotted in Figure 26 against temperature and distance above the tuyère level. The results used are taken from the integrated values obtained for the various planes.

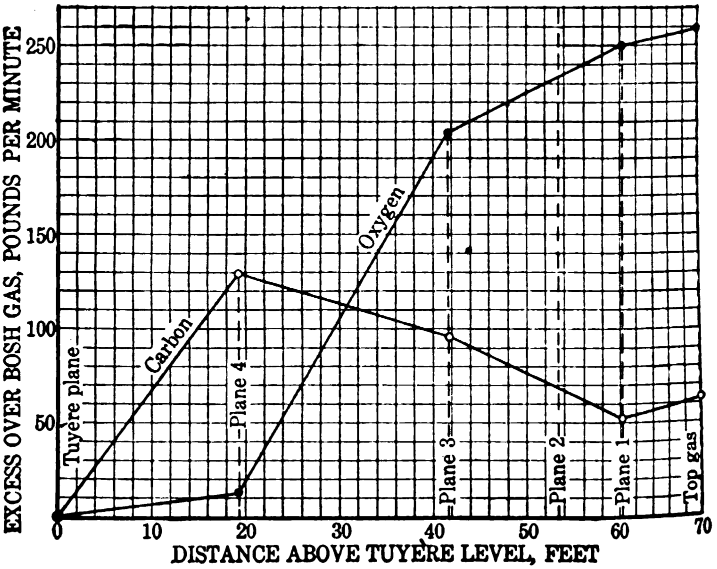

FIGURE 25.—Relation between excess C and O_2 in gases compared with bosh gases and distance above tuyères

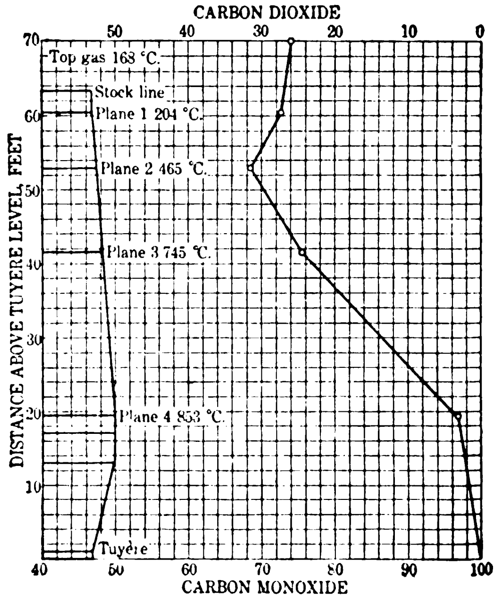

FIGURE 26.—Relation between percentage of CO_2 and CO and distance above tuyère level. $CO_2+CO=100$ per cent

TABLE 19.—*Comparison between bosh gas and the composition of gases at various elevations, by volume*

Plane	Distance above tuyère level	Ratio		CO_2+CO	$O_2/100\ N_2$ $\frac{2\,CO_2+CO}{2}\times\frac{100}{N_2}$	Excess oxygen per 100 pounds of nitrogen	$C/100\ N_2$ $\frac{CO_2+CO}{2}\times\frac{100}{N_2}$	Excess carbon per 100 pounds of nitrogen	Per 100 pounds of nitrogen				CO_2, per cent $\frac{CO_2\times100}{CO_2+CO}$	CO, per cent $\frac{CO\times100}{CO_2+CO}$
		$\frac{CO_2}{CO}$	$\frac{CO}{CO_2}$						CO_2	CO	H_2	N_2		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Ft. in.													
Top	....	0.354	2.84	38.00	39.9	+13.4	31.7	+5.3	16.0	36.8	3.3	100	26.1	73.9
1	60 4	.382	2.60	37.34	39.2	+12.8	31.0	+4.6	16.9	44.4	3.1	100	27.6	72.5
2	53 4	.459	2.18	38.64	39.2	+12.8	32.4	+6.0	20.2	44.2	2.8	100	31.4	68.6
3	41 9	.315	3.18	37.82	38.7	+12.3	31.2	+4.8	14.9	47.2	2.7	100	23.8	76.2
4	19 3	.328	3.06	34.70	27.8	+1.2	26.9	3.5	1.7	53.2	1.2	100	3.2	96.7
Bosh gas	....	....	....	34.1	26.4	0	26.4	0	.0	52.3	1.2	100	....	100.0

Results obtained by other investigators at other furnaces by sampling the gases at the edge of the planes at various elevations are plotted in Figure 27. The results obtained by Kinney at Holt, Ala., are also shown. They have been plotted against temperature. No account has been taken of the height of the furnaces; the results from other investigations are for furnaces approximately 35 feet high.

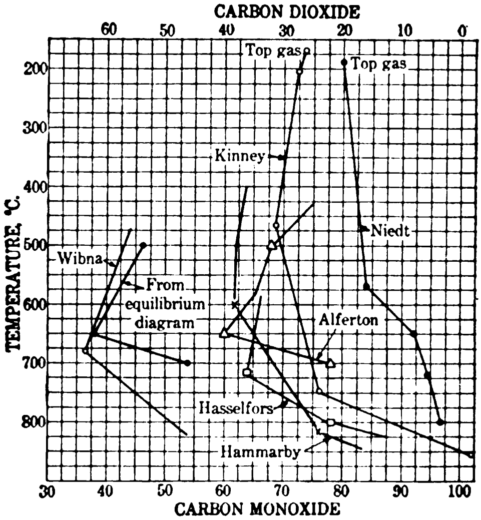

FIGURE 27.—Comparison of analyses of gas samples taken in various investigations. $CO^2+CO=100$ per cent

POSITION OF REDUCTION ZONES

The position of the zones where reduction is taking place may be approximated from the gas-sampling data. The O_2 content of either the gases or the ore could be used for determining these zones, but the former is used here. The O_2 content of the gases gradually increases with distance from the tuyère, while the O_2 in the gases at each plane, and in turn the amount remaining in the burden, may be determined. From the balance sheet of materials charged (Tables 4 to 8) it may be seen that the O_2 charged was as follows:

	O_2 charged, pounds per long ton of metal produced	O_2 charged, pounds per minute
Combined with oxides and from blast	3,007	676.6
Combined with CO_2	542	121.9
Total	3,549	789.5

OXYGEN REMOVAL

Table 18 shows that 808 pounds of O_2 were removed each minute by the gases. This result is comparable with that obtained by analysis of the materials charged. The two values represent the quantity of O_2 entering and being removed from the furnace. From calculations involving the integration of the gas analysis at each plane, the O_2 content of the gases has been determined (see column 16).

Table 20 gives the amounts of O_2 removed from each plane.

TABLE 20.—*Oxygen removed at the various planes*

Plane	Total O_2 removed in gas per minute, pounds [1]	O_2 removed from burden per minute, pounds [2]	Difference [3]	([4])	Per cent O_2 from ore removed between planes indicated	Cumulative per cent
	1	2	3	4	5	6
Top gas	808	276				
Plane 1	798	266	10	10	6.5	6.5
Plane 3	779	247	19	19	12.4	18.9
Plane 4	562	30	217	95	61.6	80.5
Bosh	532	0	30	30	19.5	100.0
			276	154	100.0	

[1] From Table 18, column 16.
[2] Column 1. Oxygen in bosh gas = 532 pounds.
[3] O_2 removed between various planes.
[4] O_2 removed between various planes; 122 pounds deducted from oxygen removed between planes 3 and 4 for calcination of limestone.

Analyses of limestone removed from the hole at plane 4 have shown that the stone is calcined by the time it reaches this level, and since the temperature and pressure at which limestone is calcined are known, it can safely be said that calcination has occurred between planes 3 and 4. This conclusion is borne out by the results shown in column 3 of Table 20; 217 pounds of O_2 is removed between planes 3 and 4 out of a total of 276. The balance sheet of materials (Table 5) shows that 122 pounds of O_2 was charged with the limestone; this oxygen is obviously being removed between planes 3 and 4, and hence has been subtracted from the results in column 4, which therefore shows how much O_2 is being removed from the oxides in the burden. From this the percentage and cumulative percentage have been calculated. The culminative percentage, or the percentage reduction which has been effected by the time the ore has reached the various planes, has been plotted in Figure 28.

The results show that 6 per cent of the O_2 of the ore burden has been removed between the stock line and plane 1, 12.4 per cent between planes 1 and 3, 61.6 per cent between planes 3 and 4, and 19.5 per cent between plane 4 and the tuyère level. Column 6 of Table 20 shows that 80.5 per cent of the O_2 of the ore should be removed by the time the burden reaches plane 4, which is 19 feet 3 inches above the tuyère level. Table 24 shows that the iron in three samples taken at plane 4 was in the following form: Fe, 84.5 per cent; FeO, 5.2 per cent; and Fe_2O_3, 10.3 per cent. In other words, there were 95.52 parts of Fe and 4.38 parts of O_2. The original ore, charged as Fe_2O_3, contained 95.52 parts of Fe and 30.5 parts of O_2. At hole 4 the relation of O_2 to that in the original ore was $\frac{4.38}{30.5}$, or 14.4 per cent, which means that 85.6 per cent of the O_2 in the ore as charged had been removed by the time the ore had reached plane 4. The calculated result from gas analyses gives 80.5 per cent.

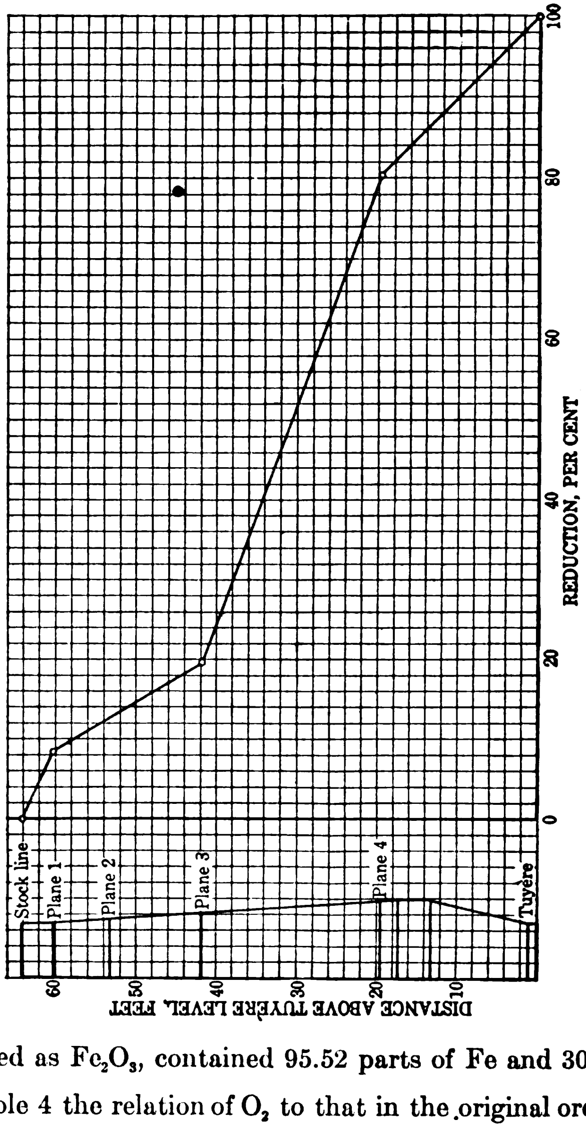

FIGURE 28.—Relation between distance above tuyère level and percentage of reduction

TEMPERATURE AND PRESSURE OBSERVATIONS

TEMPERATURES

Table 21 gives the results of temperature observations in various parts of the furnace. The temperatures were recorded by base-metal and Pt-Rh couples. On planes 1, 2, 3, and 4 the results are given for temperatures at the inwall, and on planes 3 and 4 for points in center of the plane. The temperatures at the center of planes 4 and 6 (tuyère plane) were recorded with a Pt-Rh couple. The

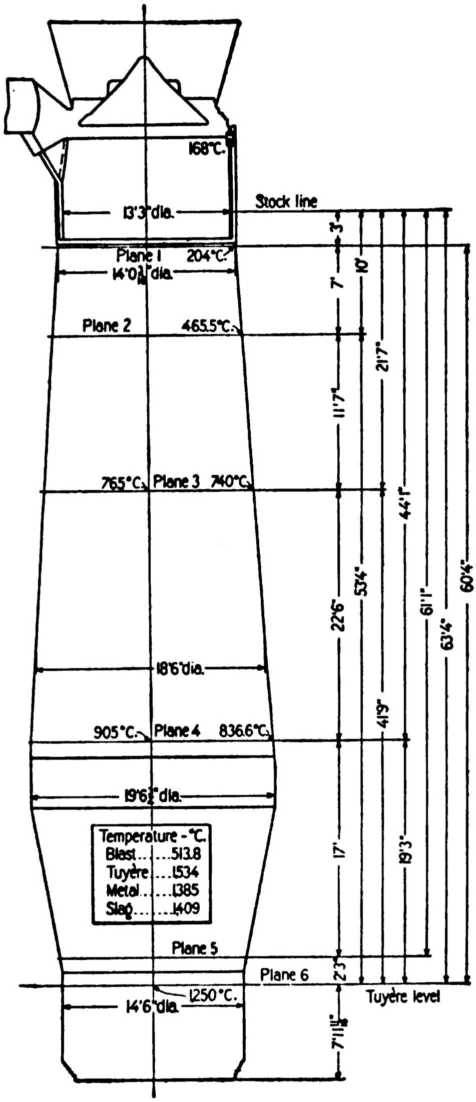

FIGURE 29.—Results of temperature observations at various points in the furnace

tuyère, slag, and metal temperatures are the result of several thousand optical pyrometer readings taken over the period of gas sampling. Figure 29 shows these results. Temperatures of the wall of the furnace taken at various distances from the steel shell to the inwall during the drilling of the gas-sampling holes through the shell have been reported elsewhere by Kinney.[20]

TABLE 21.—*Temperature observations at various points in the furnace*

Point of observation	Distance below stock line	Distance above center line of tuyères	Temperature at inwall	Temperature at center of of plane
	Ft. in.	*Ft. in.*	*° C.*	*° C.*
Top gas			168.0	
Plane 1	3 0	60 4	204.0	
Plane 2	10 0	53 4	465.5	
Plane 3	21 7	41 9	740.1	765
Plane 4	44 1	19 3	836.6	905
Plane 5	61 1	2 3		
Tuyère	63 4		[1] 1,534.0	1,250
Blast			513.8	
Slag			[1] 1,409.0	
Metal			[1] 1,385.0	

[1] Optical pyrometer observations.

PRESSURES

Results of pressure observations taken with mercury and water manometers appear in Table 22 and Figure 30, where they are compared with results obtained by two other investigators.

TABLE 22.—*Pressure observations at various elevations*

Plane	Point of observation, distance above tuyère level	Pressure, pounds per square inch	Plane	Point of observation, distance above tuyère level	Pressure, pounds per square inch
	Ft. in.			*Ft. in.*	
		[1] 16.85	3	41 9	3.7
6	(2)	15.5	2	53 4	2.3
4	19 3	10.4	1	60 4	.45

[1] Blast pressure. [2] Hearth.

DISCUSSION OF TEMPERATURE AND PRESSURE OBSERVATIONS AND COMPARISON WITH RESULTS BY OTHER INVESTIGATORS

The outstanding feature of the temperature observations in the interior of the furnace is the temperature at the center of the hearth level. The tuyère temperatures, as recorded by several hundred observations with an optical pyrometer, average 1,534° C., but this is probably many degrees below the actual temperature of the interior of the combustion zone. The temperature as measured by a couple at the center of the hearth is 1,250° C.,o r approximately 300° C. lower than the observed temperature of the tuyères. Relative temperature measurements of the hearth at the tuyère level were taken with a water-cooled sampling tube. The volume and temperature of the water entering and leaving the tube were known before the tube was placed in the furnace. Relative temperatures were then found by measuring the increase in temperature of the water flowing from the tube as it was set at various distances from the nose of the tuyère. The results showed marked increase in temperature in the combustion zone to a point where the CO_2 in the gases was at a maximum; this was to be expected because the carbon of the coke was being oxidized to CO_2. From this point on to the center of the hearth the results showed marked decrease in hearth temperature because of the reduction of CO_2 to CO and the accompanying consumption of heat. The actual temperature as measured with the couple was 1,250° C.; it has been recorded in Figure 29 and Table 21.

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[20] Kinney, S. P., "Furnace lining wears unevenly": Iron Age, vol. 115, June 4, 1925, pp. 1639-40. "Iron hottest at middle of cast"; Ibid., vol. 116, Aug. 20, 1925, pp. 466-667; 514-15.

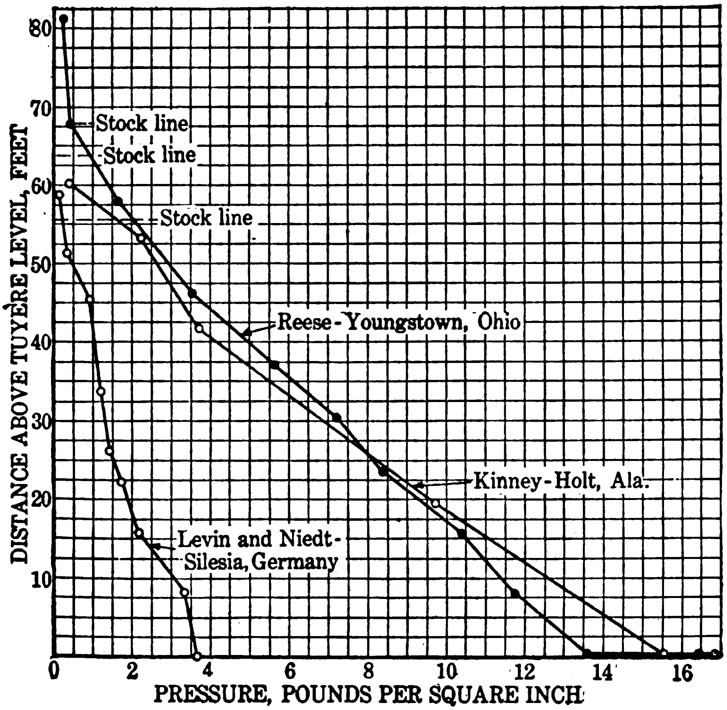

FIGURE 30.—Pressure readings compared with results of other investigators

Temperatures at the inwall of the furnace are lower than the temperatures at the center of the same plane. Temperatures at the inwall were relatively easy to find, and are shown in Figure 29 and

Table 21 for planes 1 to 4; results are also given for the temperature at the center of planes 3 and 4. Temperature observations at the center of planes 3 and 4 were made with some difficulty, because the hot descending stock bent the couples. When couples inserted in one-fourth-inch pipes were pushed through and extended 8 or 10 inches beyond the end of the water-cooled sample tube there was always doubt as to whether or not the reading was affected by the water-cooled element in the gas-sampling tubes. To drive these fragile couples into the stock was difficult. When heavy-walled iron protection tubes without water-cooled elements were driven through the stock they were bent downward as the stock descended. The observations in the center of planes 3 and 4 are therefore probably low, but they are presented as a matter of record. The difficulties encountered in the upper part of the stack were not met in the hearth plane.

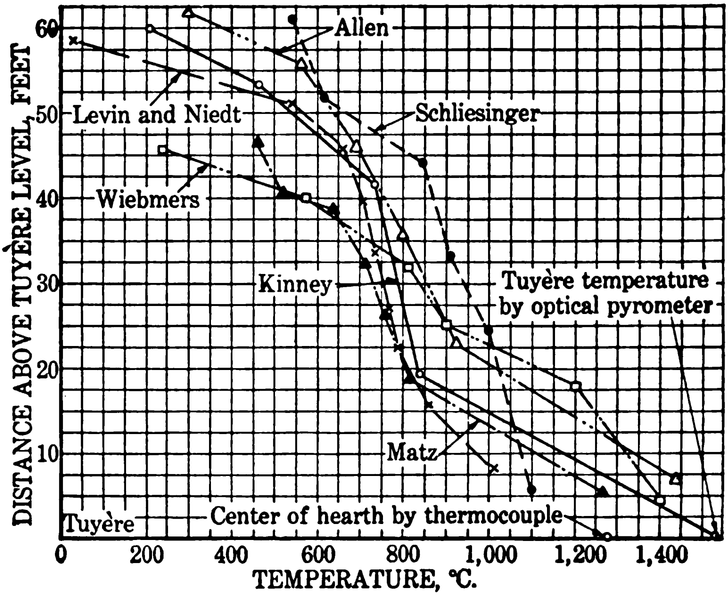

FIGURE 31.—Temperature at various elevations at inwall compared with results obtained at other furnaces

Temperature readings at various points in the furnace are compared with the results recorded by other observers in Table 23 and Figure 31.

Various investigators have recorded temperature and pressure observations at a number of furnaces, but the observations on the furnace at Holt were for the purpose of making certain gas calculations.

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TABLE 23.—*Temperature observations compared with results obtained by other investigators*

Investigator	Schleisinger	Metz	Levin and Niedt	Wiebmers [1]	Allen	Kinney
Year	1911	1913	1911			1923
Furnace at	Oberhousen	Luxemburg	Silesia	Glaiwitz		Holt
Dimension:						
Total height feet	128	71.0	65	48.5	80	90
Tuyères to stock line feet	81	52.4	61	45.3	66	63.33
Tuyères to top of bosh feet	19	21.2	21.2	18.2	23	13
Blast temperature ° C.		835	600	450		514
Top gas temperature do		165	160	260	200	168
Tuyère temperature do						

	Schleisinger		Metz		Levin and Niedt		Wiebmers [1]		Allen		Kinney	
	Distance above tuyères	Temperature	Distance above tuyères	Temperature	Distance above tuyères	Temperature	Distance above tuyères	Temperature	Distance above tuyères	Temperature	Distance above tuyères	Temperature
	Feet	° *C.*	*Feet*	° *C.*	*Feet*	° *C.*	*Feet*	° *C.*	*Feet*	° *C.*	*Feet*	° *C.*
									62	300	60.33	204
	61.0	550			58.6	28						
									56	560	53.33	466
	51.9	620			51.3	540						
									46	690		
			46.8	462	45.6	660	45.3	240				
	44.2	850									41.75	740
			40.6	522			40.0	575				
			38.6	636	39.8	710						
									36	800		
	33.1	910	32.5	713	33.6	735	32.2	815				
			26.7	768	26.8	770	25.0	900				
	24.6	1,000			22.4	795			23	925		
			19.2	817			18.2	1,200			19.25	836
					15.6	860			16	1,010		
					8.3	[2] 1,010				1,440		
	5.6	1,000	5.4	1,263								
							4.9	1,400				
					3.2	[2] 1,715						
Tuyère level	0									1,768		1,534

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[1] Wiebmers, —, ["Temperature observations in Gleiwitzer blast furnace"]: Ztschr. Berg.- Hütt. u. Salin.-Wesen, Bd. 22, p. 288. See also Jüptner, Hans von, Beiträge zur Hochofentheorie. Leipzig, 1921, p. 122.

[2] Estimated.

ANALYSIS OF SAMPLES OF STOCK RECOVERED FROM THE INTERIOR OF THE FURNACE AT PLANE 4

One object of this investigation was to determine the reduction of the descending charge. Two methods could be used: (1) Gas sampling across the various planes, or (2) analysis of representative samples of stock removed from the planes.

At plane 4 an attempt was made to obtain a number of representative samples of stock by stoking and hooking 26 to 200 pound samples through the gas-sampling holes into an air-tight container. The samples were allowed to cool in a reducing atmosphere and were later removed for analysis.

Table 24 gives the results of the anaylsis of three samples, whose iron content is based on 100 per cent. The results show that 84.5 per cent of the total iron in the sample was in the form of metallic iron Fe, 5.2 per cent in the form of FeO, and 10.3 per cent in the form of Fe_2O_3.

The results above will be used as a basis of comparison later with results obtained by means of deductions from the analyses of gas samples. More detailed analyses of the various constituents of the charge removed from the gas sample holes will be reported in another paper.[21]

TABLE 24.—*Form of iron at plane 4, per cent*

Sample No.	Weight of sample, pounds	Iron as—			
		Fe	FeO	Fe_2O_3	Total
1	26	88.5	3.9	7.6	100.0
2	200	80.1	6.7	13.2	100.0
3	100	85.0	4.9	10.1	100.0
Average		84.5	5.2	10.3	100.0

Results of stock sampling show that 84.5 per cent of the iron has been reduced at plane 4, although integration of the analyses of gas samples indicates 80.5 per cent. Analyses of gas samples are probably the more reliable because they represent samples taken at small intervals between the inwall and the center of the furnace on a number of days; the stock samples, also taken on a number of days, were from points nearer the wall than the center of the furnace

HEAT BALANCE AND DISTRIBUTION OF WORK

The amount of reduction that takes place between each plane has been calculated from the results of gas sampling and checked by means of stock samples taken at plane 4. If these data are used as a basis of calculation, the amount of heat consumed by the work of reduction in each section of the furnace can be determined. Table 25 gives a heat balance constructed from the data in Tables 3 to 8.

TABLE 25.—*Heat balance*

	B. t. u. per ton of metal	Per cent
HEAT PRODUCED		
1. Combustion of C to CO	7,371,759	51.0
2. Combustion of C to CO_2	4,784,637	33.1
3. Heat in blast (including moisture)	2,316,539	15.9
Total heat	14,472,935	100.0
HEAT CONSUMED		
1. Reduction of iron oxides	5,577,086	38.4
2. Reduction of MnO, P_2O_5, and SiO_2	825,832	5.7
3. Calcination of carbonates	1,176,470	8.1
4. Dissociation of moisture	1,030,464	7.2
5. Carried off with the iron	1,086,400	7.5
6. Carried off with the slag	1,500,632	10.4
7. Carried off with gases (dry)	1,083,650	7.5
8. Carried off with moisture in top gas	651,819	4.5
Total heat accounted for	12,912,353	89.3
Heat unaccounted for	1,560,582	
Heat unaccounted for, per cent		10.7

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[21] Kinney, S. P., Analysis of Materials in the Blast Furnace.

Table 26 has been compiled on the basis of the available heat, on the assumption that all the C is burned to CO_2 and all the H_2 to H_2O. From the gas samples it is assumed that 80.5 per cent of the work of reduction of the iron oxides is done above the level of plane 4.

TABLE 26.—*Distribution of heat*

	B. t. u. per long ton of metal	Total	
		Per cent	*Per cent*
AVAILABLE HEAT			
Combustion of C to CO_2	30, 695, 328	91. 10	....
Combustion of H to H_2O	685, 860	2. 04	....
Heat carried in with blast	2, 316, 539	6. 86	100. 0
Total available heat	33, 697, 727	100 00	100. 0
HEAT CONSUMED IN STACK, ABOVE PLANE 4			
Calcination of stone	1, 176, 470	3. 4	....
Reduction of 80.4 per cent of iron oxides	4, 473, 454	13. 3	....
Drying charge	651, 819	1. 9	18. 6
HEAT CONSUMED IN BOSH AND HEARTH			
Reduction of 19.5 per cent of iron oxides	1, 083, 632	3. 2	....
Reduction of MnO, P_2O_5, SiO_2	825, 832	2. 5	....
Dissociation of moisture	1, 030, 464	3. 1	....
Sensible heat:			
In iron	1, 086, 400	3. 2	....
In slag	1, 500, 632	4. 5	16. 5
HEAT LOST VIA TOP GASES, HEAT LOSS, ETC.			
Sensible heat in top gas	1, 083, 650	3. 2	....
Heat value of top gases	17, 473, 670	51. 9	....
Heat loss	1, 560, 582	4. 6	....
Carbon in flue dust	586, 810	1. 7	....
Carbon in metal	1, 164, 312	3. 5	64. 9
	33, 697, 727	....	100. 0

Table 26 indicates that 18.6 per cent of the available heat is consumed above plane 4; of this, 13.3 per cent is used in reducing 80.5 per cent of the iron oxides, 3.4 per cent in calcination, and 1.9 in drying the charge. In the bosh and hearth 3.2 per cent is consumed in reducing iron oxides; 2.5 in reducing MnO, P_2O_5, and SiO_2; 3.1 per cent in dissociating moisture, etc. The table also shows that even though approximately 85 per cent of the carbon is burned at the tuyère level, more work is done in the stack above plane 4 than in the bosh and hearth. It is indicated that 18.6 per cent of the heat is consumed in the stack, and 16.5 per cent is consumed in the hearth and bosh.

Table 26 shows that the distribution of the total available heat used in reducing the oxides is as follows: Above plane 4, 13.3 per cent; hearth and bosh, $3.2+2.5=5.7$ per cent. From these data and the data in Table 20, column 5, showing the percentage reduction between each plane, the heat used between the various planes in reduction may be calculated. Results of such calculations show that of the total available heat 19 per cent is used in the reduction, 1.24 per cent between the stock line and plane 1, 2.36 per cent between planes 1 and 3, 11.70 per cent between planes 3 and 4, and 3.70 per cent in the bosh and hearth below plane 4.

DISCUSSION OF RESULTS AND RECOMMENDATIONS

DISTRIBUTION OF STOCK

In common furnace practice, ore is charged so that the greater part of the oxides is distributed near the wall; the coke has a smaller angle of repose and is generally distributed more evenly over the area of the stock line. There is therefore more ore near the walls of the furnace and a greater proportion of coke in the center.

GASES AT CENTER AND SIDES OF FURNACE

The ore charge is distributed near the walls and almost directly over the combustion zones. This condition tends to keep the center of the shaft porous and open. The gases probably follow the path of least resistance, due to the difference in porosity of the charge in the stack. It therefore happens that more gas may be passing through a unit area in the center of a plane than near the edge. The gases in the central column of the stack will not do as much work of reduction per unit area as those passing up through the sections near the wall, because there is less iron oxide exposed. It is logical therefore to find in the modern blast furnace a part of the center of the shaft where there are gases very low in CO_2. The presence of these gases lowers the average CO_2 content of those entering the top gases and in turn the general efficiency of the furnace.

Here the reverse condition might be pictured; in passing, it might be said that an experiment has been tried in American practice, as follows: The ore was so charged that it was thrown to the center of the shaft and the porous part of the charge, containing a major part of the coke, to the wall. A poorly working furnace resulted in a short time.

UNEVEN REDUCTION

The center of the column was tightly packed with iron oxides; the outer part, which represents about 70 per cent of the volume of the shaft, contained a minimum of iron oxide. As a result of this condition, gases low in CO_2 emerged from the outer part of the column and gases of a high CO_2 content from the smaller and central part. One part of the shaft had too much work to do, while the outer part had too little. Two results followed—a cold hearth, due to channeling of unreduced iron oxides down through the center of the shaft, and gases along the wall.

Neither of the two conditions outlined above is ideal. In the first condition, which exists in modern practice, high CO_2 emerges from the outer part of the stock column; and in the second, the high CO_2 comes from the center of the shaft. If gases of equal CO_2 content were emerging from all parts of any plane parallel to the hearth, a third and much more ideal condition would ensue. It would necessitate an equal flow of stock downward and an equal and uniform flow of gas upward, and progressively uniform reduction would then be taking place throughout the stock column.

COMBUSTION ZONES

The combustion zones control the movement of the stock in the shaft of the furnace; if these zones could be arranged to cover all of the hearth area, the coke would be burned and the stock would descend uniformly. Here it might be pertinent to give some examples of the effect of the extent and arrangement of combustion zones on the movement of stock in the column. Comparison of the results of gas sampling in the 300-ton furnace at Holt and the Bureau of Mines 6-ton furnace at Minneapolis follows.

COMPARISON OF ANALYSES OF GAS SAMPLES FROM THE 300-TON AND 6-TON FURNACES

In Figures 32 and 33 analyses of gas samples from the 300-ton furnace are compared with those from the 6-ton experimental furnace. Lines of equal CO_2 content of gases are plotted on furnace sections in elevation to emphasize the differences in the two stacks. The two figures show that there is a marked difference in the working of the two furnaces. For example, the high CO_2 gases are found near the wall of the 300-ton furnace but in the center of the 6-ton furnace. The authors believe that the CO_2 content of the gases bears some relation to the stock movement in the furnace and that the highest CO_2 is found where the movement of stock is most rapid. It has been pointed out that the movement of the stock is controlled by the extent of penetration of the combustion zone. In the 6-ton furnace the hearth was small; the combustion zone covered the whole area, in fact overlapped. In the full-size furnace the combustion zones are at the nose of each tuyére, and are small in comparison to the total hearth area. As stock moves directly over the combustion zone, movement in the 6-ton furnace would take place more evenly across any plane. As the zones overlapped the stock movement might have been faster in the center than at the wall on account of the restricted combustion space, while in the 300-ton furnace the movement was more rapid near the wall and comparatively slow in the center. As it has been shown that the gas flow is probably fairly equally distributed in the stack of the furnace, the gases containing the highest amounts of CO_2 would be expected to be near the wall. The results here show

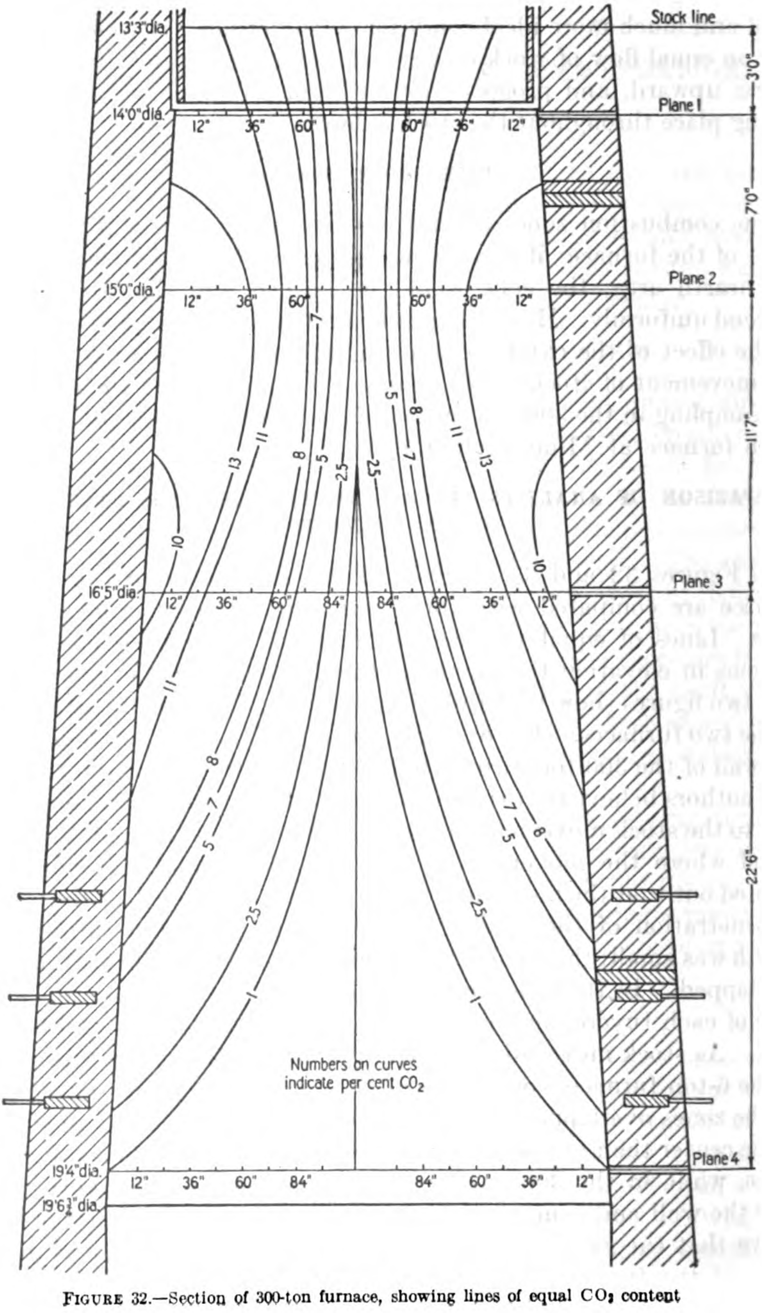

FIGURE 32.—Section of 300-ton furnace, showing lines of equal CO_2 content

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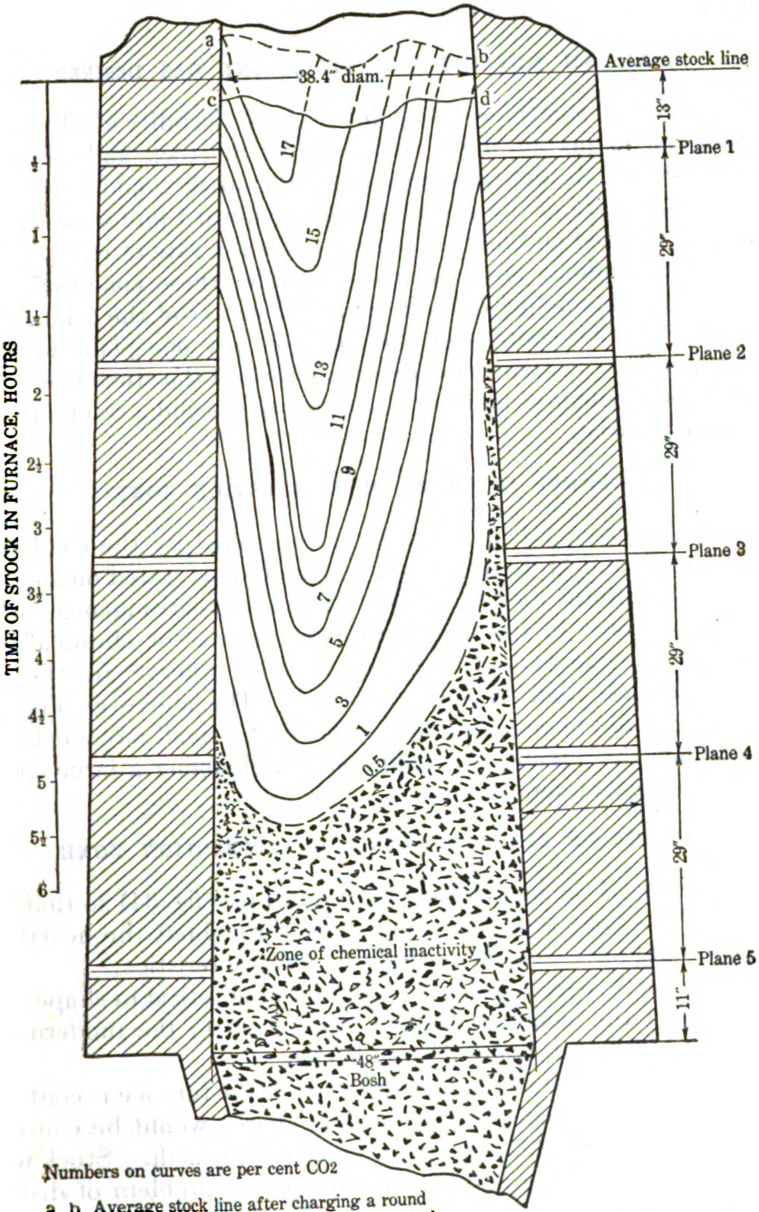

Numbers on curves are per cent CO2

a b Average stock line after charging a round
c d Average stock line before charging a round

FIGURE 33.—Section of the Bureau of Mines experimental furnace, showing lines of equal CO_2 content

distinctly that bosh gas is passing upward through the center of the furnace. This gas has done no work of reduction and is diluting the gases that contain more CO_2.

UNIFORM MOVEMENT OF STOCK AND GAS DESIRED

Conclusions from these data point to the desirability of adjustments in practice to permit more uniform flow of stock and gas in the furnace shaft. Under ideal conditions the stock would move downward uniformly and the gas would move upward uniformly through a uniformly sized and mixed charge, where the rate of reduction was uniform throughout any one plane. Under these conditions there would be no channeling of bosh gas at the center of the column. As a result, the CO_2 content of the gases on any one plane would be uniform and the content would increase toward the stock line. Such a condition would give higher CO_2 in the top gas and a resultant lower coke consumption.

CHANGE IN SHAPE OF COMBUSTION ZONE

As stock movement in the shaft is controlled by the combustion zone, Kinney and McKenzie [22] have suggested, as stated on an earlier page, that uniform flow may be obtained by rearrangement of the combustion zones in the hearth to a rectangular or elliptical form. Such an arrangement had been suggested by others [23] for the small circular furnaces used 50 or 75 years ago. The above results show that there would be no advantage in making a small circular furnace rectangular; the advantage would come in changing a large circular furnace to the rectangular form.

EFFECT OF REARRANGEMENT OF COMBUSTION ZONE

If the shape of the hearth were rearranged (see fig. 34) so that combustion of the coke took place uniformly throughout the hearth, the furnace would have some of the following characteristics:

1. The hearth area would be rectangular or elliptical in shape, twice the length of the combustion zone (80 inches) in the modern blast furnace in width and of any desired length.
2. Because the flow of stock in the shaft of the furnace is controlled by the combustion zones the descending charge would be consumed evenly and regularly throughout the area of the hearth. Stock would then move more evenly and the now important problem of distribution would be of less moment.

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[22] Kinney, S. P., and McKenzie, F. B., "Proposed hearth and bosh construction": Iron Age, vol. 115, Feb. 12, 1925, pp. 476–478.

[23] Alger, C. C., Improved Smelting Furnace: U. S. Patent 677, Mar. 29, 1859; U. S. Patent 17659, June 30, 1857.

Raschette, Woldemar, "Improved blast furnace": U. S. Patent 43274, June 21, 1864. Universal Blast and Smelting Furnace. 1864, 11 pp.

3. The hearth area would have a higher and more uniform temperature throughout which would, in turn, permit greater ease and latitude of control.

4. Removal of the central part of the hearth where no combustion is taking place would relieve the hearth of a zone that is much cooler than any other part. Contamination and cooling of the metal from this stagnant zone could not take place.

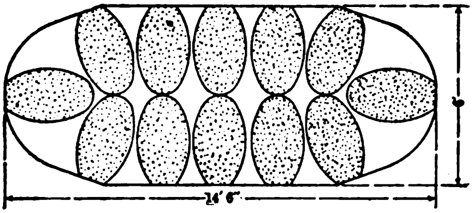

FIGURE 34.—Diagram showing oxidizing and reducing zones in a proposed blast-furnace hearth

5. The capacity of a furnace constructed to conform to a hearth which had two axes, one longer than the other, will be increased not by increasing the diameter of the circle, as is done in current practice, but by increasing the length of the major axis.

CONCLUSIONS

Some of the most pertinent points indicated by the results of gas sampling on planes 1 to 6 are as follows:

RESTRICTED COMBUSTION ZONE

Combustion of coke in the hearth of the furnace is taking place in a comparatively restricted zone at the nose of each tuyère. Oxygen of the blast is consumed 30 inches in a horizontal direction and 27 inches in a vertical direction from the center of the nose of the tuyère. The CO_2 is reduced at a horizontal distance of 40 inches and probably at a like vertical distance. It may therefore be concluded that the process of combustion is taking place in a restricted zone within 40 inches of the nose of the tuyère.

INEFFICIENCY OF COKE

As combustion is taking place in a restricted zone at the nose of each tuyère, the carbon of the coke is being rapidly converted from the solid to the gaseous phase in this restricted combustion zone. A void is thus created toward which the stock is constantly flowing from all parts of the shaft. In other words, the extent of the combustion zone controls the movement of the stock in the upper part of the furnace. Stock lying directly over the combustion zone, like coal directly over a hole in the bottom of a coal bin, will move more rapidly in its descent toward the tuyères than that at points farther removed, say, in the center of any plane. This fact has also been pointed out by Royster and Joseph[24] in experiments on models. These deductions lead to the conclusion that the movement of stock in the shaft is not uniform.

It is pointed out that as the product of combustion is CO, the net heat produced per pound of carbon burned is a constant—29,160 gram-calories—and all tuyères are similar in this respect.

RESTRICTED GAS FLOW

Excess of nitrogen in the center of the furnace, at the tuyère plane, and at plane 5 indicates restricted gas flow in the hearth and bosh of the furnace and reactions which produce CO, such as the oxidation of iron, the formation of cyanides, or the so-called direct reduction of metallic oxides.

BOSH GAS

The gases on plane 4, which is 19 feet 3 inches above the center line of the tuyères, have been shown to have practically the composition of bosh gas; this composition is constant throughout the planes.

The analyses of gas samples on planes 1, 2, and 3 show certain similar characteristics. First, there is a high CO content in the gases near the wall and to a distance of about 40 inches from the wall. Second, after the 40-inch point has been passed the CO_2 falls rapidly, as the center of the furnace is approached, to approximately the proportion in bosh gas.

Gas sampling and integration of the CO_2 curves show that the CO_2 content of the gases increases with distance above the tuyère until plane 2 is reached; the gases then decrease in CO_2 content until the composition of top gas is attained at the top of the furnace.

Comparison of the average calculated CO_2 in the top gas from integration of the CO_2 curve from plane 1 and the observed average CO_2 content of the top gases indicates that the gas flow per unit area of plane 1 is approximately uniform, but does not indicate uniformity of flow in the lower part of the shaft.

CAUSE OF UNEVEN DISTRIBUTION OF CARBON DIOXIDE

If it is assumed that the flow of gas per unit area of any one plane is uniform and the descent of stock is not, because of the restricted zones of combustion, a furnace shaft can be pictured in which the gas flow is fairly uniform or possibly slightly faster in the center from the porosity of the charge, and in which the movement of stock downward is comparatively rapid close to the walls and for 40 inches from them and comparatively slow in the center. If the iron oxide were charged so that it would lie in uniform layers, then through the nonuniform flow of stock more iron oxide would pass any unit area of the 40-inch ring per unit of time than would pass a like area in the center of the plane. It is known, however, that the greater part of the oxide is near the wall, therefore the amount of reduction is greater in the outer ring per unit of area and time, which accounts for the resultant higher CO_2 in the gases from this part of any plane. As the movement of stock in the center area is comparatively slow, the iron oxide is rapidly reduced with a small accompanying effect on the CO_2 content of the gases. The cause of this condition—that is, high CO_2 near the wall and low CO_2 in the center—can be directly attributed to the restricted combustion zones at the tuyère level and the resultant uneven flow of stock throughout the shaft.

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[24] Royster, P. H., and Joseph, T. L., "Effect of coke combustibility on stock descent in blast furnaces": Trans. Am. Inst. Min. and Met. Eng., vol. 70, 1924, pp. 224–233; discussion, pp. 233–238.

Again, if the method of charging a furnace is considered, the distribution of ore on any plane is uneven; the largest amount per unit area tends to be near the walls of the furnace and a small amount in the center. The fine material remains near the wall and the coarser tends to go to the center. This condition would bring us to the same conclusion—that is, that more reduction per unit area and time is taking place near the wall, which would account for the higher CO_2 at that point.

PROBABLE EFFECT OF REARRANGEMENT OF COMBUSTION ZONE

It is suggested that a rearrangement of the combustion zone would produce a more uniform flow of stock, more efficient contact between gas and solid, and a resultingly lower consumption of coke.

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